SDE _ FINAL TECHNICAL REPORT

*EC TENDER #: ENER / C2 / 2016-502*

# solar decathlon europe

## analysis of the results: final technical report

*PNO Consultants*
*Energy Endeavour Foundation*
*Universidad Politecnica Madrid*
*Bergische Universität Wuppertal*
*Technische Universiteit Delft*

Funded by:
European Commission

solar
decathlon
europe

# summary

Solar Decathlon Europe | Tender ENER/C2/2016-502 | 2016 - 2020:

Basis for this tender is Action 50 “Support to the European Innovation Partnership on Smart Cities and Communities and its Market Place”, Horizon 2020 Work Programme 2016 – 2017. Final objective is to ensure constant and high quality support to the Market Place of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) and the Solar Decathlon Europe (SDE) initiative.

A consortium of former SDE organisers consolidated the results of the SDE competition event, held four times to date in Europe. In a series of four thematic reports, the group distilled the quintessential elements relevant to European partners. With fact sheets for specific audiences , the team has created a portfolio of documents that showcase actions, impact and importance of the SDE competition. The SDE has inspired millions through its unique combination of youthful enthusiasm, vigorous competition and innovative technological solutions to real-world challenges. Participants have demonstrated that resource optimisation is possible by being intrepid, ingenious and responsible.

Results of this tender will feed into the Smart Cities Information System, launched with the support of the European Commission to collect data on projects dealing with smart cities and buildings.

solar decathlon europe

# table of contents: final technical report


| | PG |
|---|---|
| Executive Summary | 4 |
| Thematic Report 1 | 10 |
| Thematic Report 2 | 64 |
| Thematic Report 3 | 109 |
| Thematic Report 4 | 155 |
| Conclusions | 237 |
| Glossary | 248 |
| Colophon | 259 |

# solar decathlon europe

## executive summary

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS"
WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID,
BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# executive summary

The Solar Decathlon is a university-level Competition initiated by the U.S. Department of Energy in 2002. It was intended for American universities and consisted of designing, building and operating a prototype of energy-self-sufficient house, powered by the sun, and equipped with any technologies that would allow maximum energy efficiency. The final Competition phase consisted of assembling the prototypes on the National Mall in Washington D.C., where the 'Solar Village' was located, and where all the prototypes were exhibited to the public while competing in 10 different Contests that comprise the Competition (a decathlon). Its main objective was to educate the next generation of architects and engineers, making them and the public aware of the efficient use of energy, while promoting the development of integrated solar energy in houses.

The Universidad Politécnica de Madrid (UPM) participated in the next three editions of the American SD Competition: in 2005 (as the first non-American university to participate in the Competition); in 2007, and again in 2009. During the 2007 Competition, a Memorandum of Understanding (MOU) was signed between the Spanish and U.S. Governments, by virtue of which Spain would organise two editions of the Competition in Madrid, for European Universities, giving birth to the first international Solar Decathlon Competition in Europe, known as the Solar Decathlon Europe.

The Spanish Government commissioned UPM to organise the first two editions of the SDE with the aim of adapting it to European sensibilities, taking advantage of the SDE to raise awareness and educate not only European university students, but also professionals and citizens, promoting energy efficiency, renewable energy, and sustainability in our buildings and cities.

**The organising team articulated two additional major objectives to be developed:**

- To promote the innovation and generation of knowledge in systems to improve the energy efficiency of buildings, the integration of renewable energies, and the enhancement of sustainability in cities and buildings. Furthermore, this included the transfer of all this knowledge to the industry and professionals, in order to generate a critical mass of technical experts who integrate it in their daily thinking, and can apply it in their designs and technical activities.

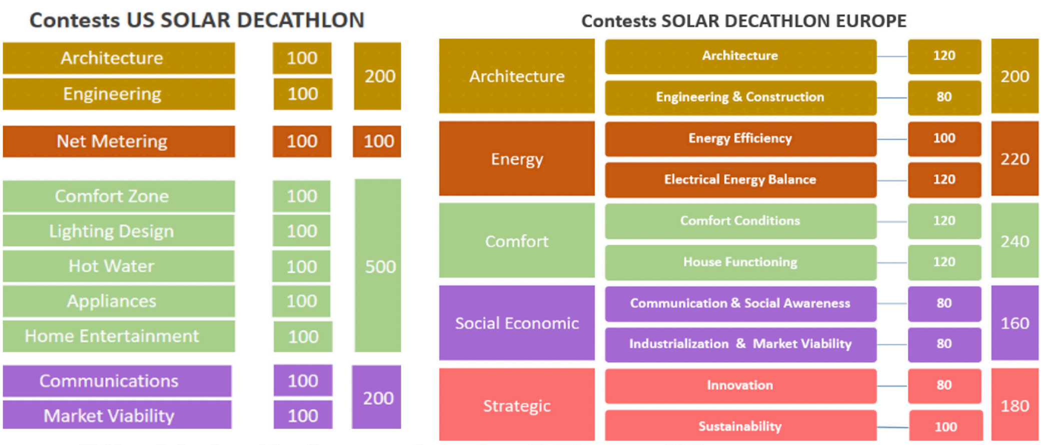
- To take advantage of the societal interest and the media attraction that the Competition awakens in the media, in order to sensitise society, from children and young people to the general public, in the responsible use of energy, the need to improve the energy efficiency of our buildings, to integrate renewable energies, and to help develop a more sustainable society.

solar
decathlon
europe

In order to meet the challenge and the proposed objectives, many changes and innovations were incorporated into the Competition in Europe. Various strategies were developed, many of them shared with the participating Decathlete Teams; some strategies were favoured by the European Commission, and many were extended and improved in the successive European editions of the SDE Competition. This helped to clearly establish a SD Competition with a European character, different from other editions held over the years in worldwide SD chapters in the United States (SDUS), China (SDC), Latin America & Caribbean (SDLAC), the Middle East (SDME), and Africa (SDA).

**The main features that differentiate SDE from previous American editions were:**

- There was a readjustment of the Competition Rules to promote innovation, energy efficiency, sustainability, industrialization, social awareness and communication. This resulted in changes in the Competition Contests, renewing around 50% of the Competition scoring with respect to the US-DOE original. The 1 000 points of the Competition were distributed in the US SD in ten Contests each with 100 points. In the SDE they were distributed according to the importance attributed to each Contest, with 120, 100 or 80 points. 400 of the points came from four Contests related to the functioning of the houses, which in the initial SDE was reduced to 120 points in one Contest, freeing up points to distribute in other Contests and new sub-contests to explicitly promote the above-mentioned European values.



**Contests US SOLAR DECATHLON**

| | | |
|---|---|---|
| Architecture | 100 | 200 |
| Engineering | 100 | |
| Net Metering | 100 | 100 |
| Comfort Zone | 100 | 500 |
| Lighting Design | 100 | |
| Hot Water | 100 | |
| Appliances | 100 | |
| Home Entertainment | 100 | |
| Communications | 100 | 200 |
| Market Viability | 100 | |

**Contests SOLAR DECATHLON EUROPE**

| | | | |
|---|---|---|---|
| Architecture | Architecture | 120 | 200 |
| | Engineering & Construction | 80 | |
| Energy | Energy Efficiency | 100 | 220 |
| | Electrical Energy Balance | 120 | |
| Comfort | Comfort Conditions | 120 | 240 |
| | House Functioning | 120 | |
| Social Economic | Communication & Social Awareness | 80 | 160 |
| | Industrialization & Market Viability | 80 | |
| Strategic | Innovation | 80 | 180 |
| | Sustainability | 100 | |

*Table 1. Solar Decathlon Contests evolution from SD US 2009 to SDE 2010.*

These contests have progressively evolved in the successive European editions, forming one of the significant points of identity of the European editions. Some of the European contests have been incorporated in successive editions in the United States, China, Latin-American, Middle East, and African editions of the Solar Decathlon.

solar decathlon europe

- Another fundamental strategic decision in the first three editions of the SDE was to assume and promote that, while the SDE fundamental consists of the university Competition, it offers great and additional potential as an event encompassing parallel awareness activities. This was a second significant point distinguishing the SDE from other editions. The Competition as a stand-alone action was examined and analysed, to the conclusion that complementary and parallel outreach and awareness activities could generate extraordinary public interest, thus maximising the attractiveness of the Competition, educational and social opportunities, powerful media impact, and the important incentives attracting sponsorship support. In short, in order to take advantage of the potential offered by the SDE, it was necessary to organise both the Competition and its associated activities in an integrated manner, providing cohesive content to attract the broad audiences. The organisation of the first editions had separate persons each assigned to manage the Competition and the event.

**The objectives and strategies were shared with the participating universities, to reach the citizens of their respective communities. It is worthy to highlight the commitment and enthusiasm of the students, their professors, and their universities:**

- Funded by the European Commission within its Intelligent Energy Programme, the 10Action project highlighted one of the most successful SDE outreach strategies. The 10Action project stimulated the development of educational and awareness activities for important target groups corresponding both to future generations (children & teenagers, and university students), and the current generation of professionals and citizens (general public, professionals, and industry). The leverage of the 10Action investment fostered dozens of activities in twelve European countries, with the participation of more than 187,000 people, amplifying the potential impact of the SDE through supported communication actions and plans.

- The SDE was promoted to amplify media impact, with wide deployment in conventional media (TV, radio, press), while stimulating broad promotion in social and digital media that has grown in successive editions. Raising awareness and attracting public visits to SDE solar villages are confirmed fundamental objectives.

- Another significant endeavour was to encourage the active participation and visits of representatives from the SD host countries and European administrations. This included the participation of the Prince of Spain (the current King), Ministers of Housing of the European Union, and the participation in all editions of multiple Ministers of organizing Governments (Spain, France, Hungary), Ambassadors of the participating Teams' countries, Presidents and regional councillors, Mayors, etc. This involvement of politicians has not only served to sensitise policy makers, but has also been in important to attract media, which in turn amplifies the social impact with favourable influence on the public.

- The strategy also included mobilising professional associations and companies with shared objectives, seeking not only their sponsorship and explicit support, but also collaborating actively with them to organise parallel events and activities that would attract professionals to the solar village. World, international, and national congresses, international meetings of all kinds, conferences, and exhibitions have been organised in the solar village, and in the most prestigious professional fairs, the headquarters of partner associations, the European Commission, and similar venues.

- Finally, in the interest of attracting our valuable public consumers to the solar village, dozens of games, educational and social awareness activities were organised in each of the first three SDE editions for each of the defined target groups. These included games and activities for children and teenagers; training visits during assembly and disassembly phases for university students of architecture and engineering; summer schools, workshops, and professional visits to the solar village. These actions were associated with congresses, conferences, workshops, and educational exhibitions for the general public, family visits, guided tours, including exchange and networking in the leisure and hospitality areas in the Village. Each contributed with material and messages of social awareness for each target group. In this sense, the synergy of the 10Action project was a key driver for the success of the first two editions, and its absence was noticeable in the successive two editions.

All these strategies have been combined with other initiatives such as the commitment of the participating universities and Teams, the creativity, enthusiasm and vigour of the students, the active participation of the European Union, the active support of governments, and the formidable work of the organisers. All of these have contributed to the success of the SDE despite the budget cuts that have always affected each edition. The Solar Decathlon Europe Competition has been consolidated with an unequivocally European character, and has successively enriched this profile so that today, Solar Decathlon Europe is recognised worldwide as one of the most solid, international, influential and attractive Competitions in the sector.

In support of the design-build-operate pedagogical paradigm, a project (annex) was initiated in the International Energy Agency's 'Energy in Building and Communities' (IEA-EBC) programme entitled 'Annex 74: Competition & Living Lab Platform'. The aim of Annex 74 is to investigate the link between competitions like the SDE and science as well as the living lab approach to both education and research. This has assisted the creation of database and knowledge platform to document SD competitions and entries.

Four editions of Solar Decathlon Europe have taken place to date: SDE10 & SDE12 in Madrid with the commitment of the Spanish Government; SDE14 in Versailles with the commitment of the French Government; and SDE19 in Szentendre under the Energy Endeavour Foundation's designation and stewardship, and the commitment of the Hungarian Government.
The next edition of SDE21 has been postponed to 2022 (a result of COVID19) in the German city of Wuppertal, under the Energy Endeavour Foundation's designation and stewardship, and commitment of the German Government.

Beyond the achievements and successes, there have also been less successful strategies and varied results from one edition to another. If the Solar Decathlon Europe is to be an effective vehicle to promote innovation and social awareness in the name of improved energy efficiency and sustainability in our buildings and cities, with a view to 'zero carbon Europe', it is imperative to document and critically analyse the development of the first four editions. This includes the analysis of the impact and influence of SDE on issues going beyond the technical, toward topics involving the capacity to influence and create correlations within the Smart Cities Community, and the improvement and potential of education and workforce enhancement.

This is precisely the approach used to measure the performance achieved in these aspects. The following Thematic Reports document the conclusions and lessons learned from the editions held so far, and provide a critical analysis with some recommendations on how to improve and enhance the potential of Solar Decathlon Europe. It has great potential to align and support the priorities and goals of the European Commission. This is the premise, the object, and the meaning of the work caried out under the contract: EC TENDER ENER/C2/2016-502: SOLAR DECATHLON EUROPE COMPETITIONS, and of the final report which is articulated in four thematic reports:

- **THEMATIC REPORT 1 _ Building Design and Construction**
- **THEMATIC REPORT 2 _ Energy Engineering**
- **THEMATIC REPORT 3 _ Increasing impact for the Smart Cities Community**
- **THEMATIC REPORT 4 _ Education and Workforce Enhancements**

These reports constitute the consolidation and documentation of the efforts undertaken to build, design, and operate 65 solar-powered houses in Europe to date. An additional eighteen houses will be assembled in Wuppertal, Germany in the summer of 2022. Beyond that, the analysis within these reports can serve to spur new innovation and further evolution of one of the most prestigious student design-build Competitions in the world.

SDE _ THEMATIC REPORT _ 1/4 _ BUILDING DESIGN & CONSTRUCTION

*EC TENDER #: ENER / C2 / 2016-502*

# solar decathlon europe

## I. building design & construction

*SUSANNE HENDEL, KARSTEN VOSS, ANDREA BALCERZAK*

*UNIVERSITY OF WUPPERTAL*

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# table of contents: thematic report I

PG

| | | |
|---|---|---|
| | **Introduction** | **11** |
| **1.1** | **Solar Decathlon Europe Houses** | **12** |
| 1.1.1 | Architecture | 13 |
| 1.1.2 | Building Size and Building Shape | 14 |
| 1.1.3 | Architecture Scoring in the Competition | 19 |
| **1.2** | **Passive Design** | **20** |
| 1.2.1 | Thermal Protection | 21 |
| 1.2.2 | Windows and Shading | 23 |
| 1.2.3 | Buffer Zones | 28 |
| 1.2.4 | Passive Ventilation | 34 |
| 1.2.5 | Further Approaches | 38 |
| **1.3** | **Constructions and Construction Materials** | **40** |
| 1.3.1 | Load-Bearing Material | 42 |
| 1.3.2 | Materials for thermal Insulation | 46 |
| 1.3.3 | Surface cladding | 47 |
| 1.3.4 | Sustainability in Construction | 53 |
| **1.4** | **Solar System Integration** | **55** |
| **1.5** | **Conclusion** | **60** |

solar
decathlon
europe

# introduction

Since the first SDE, energy efficiency in building design and construction has been a key part of the Competition. Together, both form the so-called passive approaches for the reduction of a building's carbon footprint. Over the course of time, the Competition in Europe has evolved from educating the general public on how to use renewable energy to "educate the general public about responsible energy use, renewable energy, energy efficiency and technologies available to help reduce their energy consumption"[sde14 2014, p. 1].

An essential innovation was the introduction of the sustainability contest during the transition of the SD to Europe in 2010. With that contest, a life cycle analysis and general sustainability considerations become part of the Competition. This creates a strong impact on the Team's choice of material and the construction method with regard to resource efficiency and circularity.

Since the first edition of the Solar Decathlon Europe in 2010, 65 houses have been built until 2019. As the information was available, about 50 of these houses could be evaluated for the analysis included in this report. In some cases of analysis fewer buildings were compared, but never less than 30 houses. Nevertheless, this number of comparable houses within one study shows in general the potential of the SD for research and as a source of lessons learned for the building industry. Careful and comparable documentation is a precondition but was not always achieved. There is still room for evolution in future editions.

The information used for the following analyses was part of the final Team documentation in past SDE Competitions. Information on the building design and construction of all SDE houses is documented in the database www.building-competition.org. Content will be continuously added.

solar decathlon europe

# 1.1 solar decathlon europe houses

Within the scope of this Competition, international student Teams design, build and operate these houses. To make the assembly, disassembly and transportation process possible, the houses are small, light-weight constructions. A high degree of prefabrication proved to be advantageous as the houses must be built in a short time frame and able to fully function immediately upon construction and without commissioning.

Usually the houses run through the following process

- pre-constructed at the Team's home location,
- disassembled,
- transported to the event location,
- simultaneously assembled within two to three weeks,
- tested and demonstrated for 10 to 14 days,
- again disassembled and in some cases moved back and
- assembled either at home or a new location.

Some houses were moved more frequently than others and in some cases, houses act as a road show. For example, the house of the Virginia Tech University 2010 VGT ranked second in the SDUS09 Competition. They also competed in and won the SDE10 with a further evolution, the LumenHaus. In between the two Competitions, the house travelled through the USA and stood, among other places, on Times Square (Figure 1.1) and in Blacksburg Virginia. It continued to be exhibited in the USA after the SDE10 in Madrid, for example, in the Millennium Park in Chicago. With their house, this Team demonstrated the communicational potential of a SD entry.

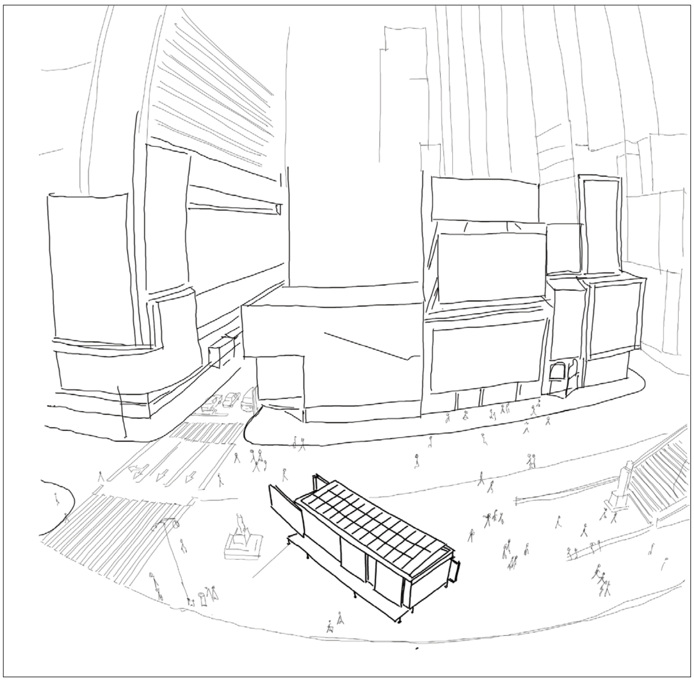


Figure 1.1: Sketch of 'The Lumen House' on Times Square. This Team presented their house at different locations in the US following their successful participation in SDUS09. Such events raise public interest outside the Competition itself. Source: University of Wuppertal, Susanne Hendel

solar
decathlon
europe

### 1.1.1 Architecture

The SDE is a truly international endeavour. Until now, two Competitions have been held in Madrid (2010, 2012), one in Versailles (2014), one near Budapest (Szentendre 2019) and one will be held in Wuppertal, Germany (2021). Competing Teams from all over the world tackle European challenges within the framework of the Competition and at the same time, reflect on their own cultural backgrounds and building traditions (Figure 1.2). Different interpretations of the same challenges and situations and different building traditions lead to a wide range of building designs.

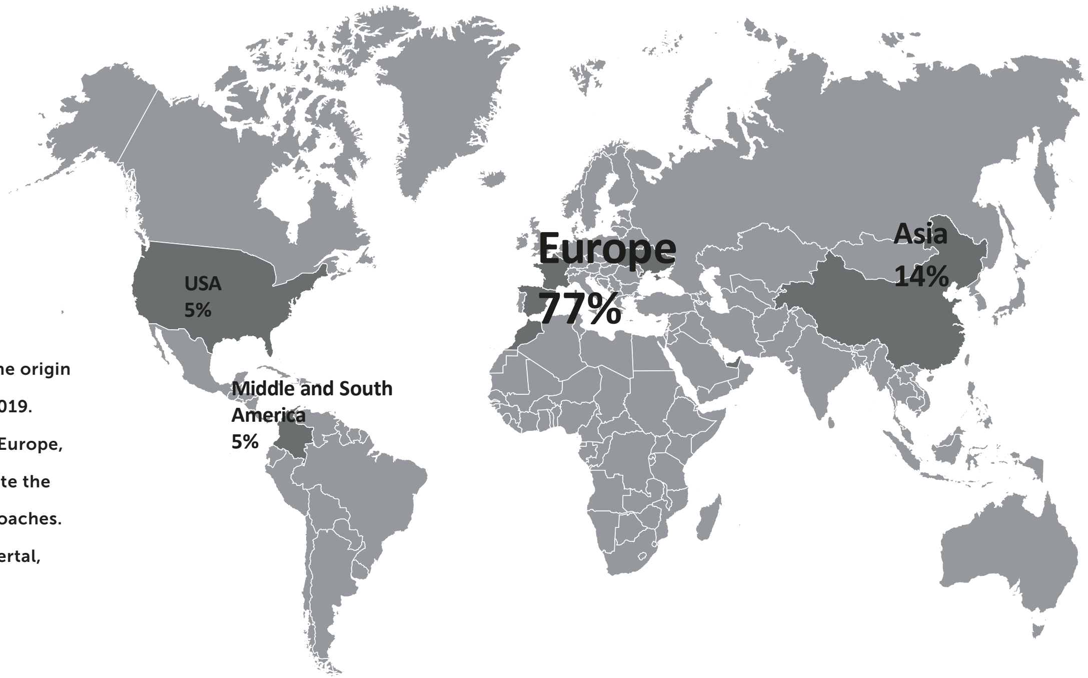



Figure 1.2: Distribution of the origin of the SDE Teams 2010 to 2019. Beside Teams from all over Europe, international Teams stimulate the diversity of the design approaches. Source: University of Wuppertal, Susanne Hendel

Unusual for architecture, most designs lack specific locations for their buildings and thus a building context. This fact is one of the main reasons why awareness of the SD is still comparatively low in the public architecture discourse. Real architecture tasks reflect the context of a specific site and are judged in relation to that. With the introduction of specific construction tasks, some of the Teams began to include context in the architecture task; examples of this can be seen in the SDE14 contributions made by the Teams DEL, ROF and OTP[1].

[1] The abbreviations refer to the name of the Teams within a Competition.

The result is a significant new dimension within the current architectural discourse. In particular, the SDE19 houses represent this development, which will be consequently continued at the SDE21. However, these buildings lack their chosen contexts during the exhibition. The lacking context at the event site may limit the architectural discussion and perception of the houses. However, first examples show that there are means and ways of creating context which can be expanded upon (Figure 1.3). Particularly suited is the innovative use of virtual reality to present the buildings in their contexts. It remains to be seen whether such approaches succeed in achieving greater visibility of the Competition in the debate surrounding architecture.

solar decathlon europe

Figure 1.3: Interior view of the SDE19 TU Delft (MOR) house. The concrete structure of the existing urban building which is the starting point of the project is visible. Source: University of Wuppertal, Katharina Simon

At the SDE19, the Team from the TU Delft built for their house MOR part of a reinforced concrete structure on the event site. The MOR Team drafted a concept for the reuse of an office building in Rotterdam. A large part of the building's space should be used in future as living space.
At the SDE site a residential unit was built to demonstrate this and recreated part of the existing reinforced concrete structure. The context is thus explained. However, the segment from the building is not easy to classify and appears unfinished due to the building task selected.

A further significant architectural aspect is the size of the buildings. The houses are only about 60m² in net floor area due to Competition Rules and the mobility required of the houses (refer to section 1.1.2). The small size of the buildings (Figure 1.4) leads to a multitude of architectural and interior design solutions for small rooms (refer to section 1.1.2). This is still uncommon in European building practice, nevertheless, it is of increasing interest with regard to compact inner city living.

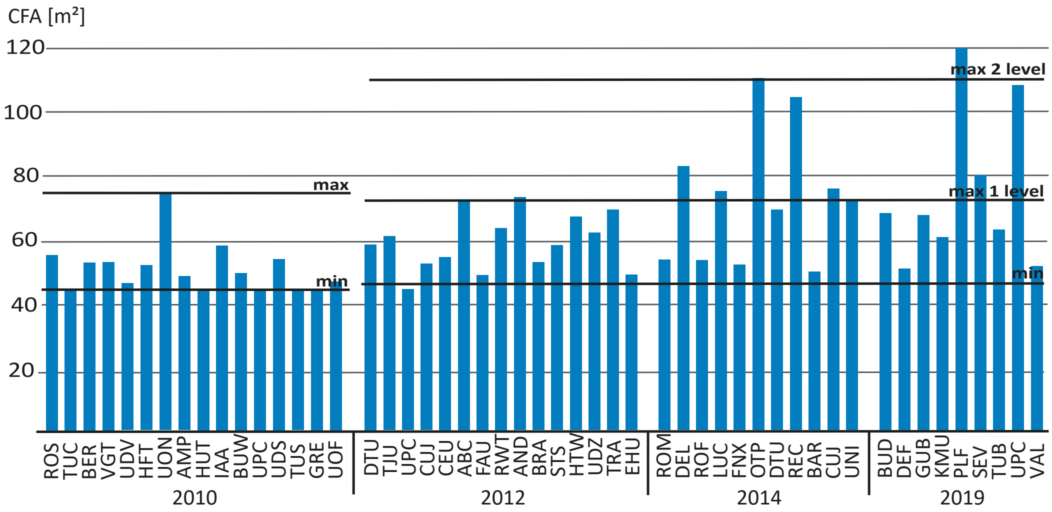
The integration of solar systems into architecture remains one of building practice's key tasks and a central design issue at the SDE. Apart from the presentation of standard systems such as on- and in-roof installations, numerous SDE projects have already contributed to improvements in the scope of solar systems within architecture, refer to chapter 1.4.

### 1.1.2 Building Size and Building Shape

The SDE gives impulses for compact and space-efficient living; the houses demonstrate options for innovative living spaces which are more space efficient than usual.
As mentioned above, SDE houses need to be space efficient due to the size restrictions specified by the Competition's Rules.

solar
decathlon
europe

Figure 1.4: Conditioned Floor Area (CFA, as defined in the Competition Rules, almost comparable to the net floor area) of the SDE houses in the Competitions from 2010 to 2019 together with the minimum and maximum building sizes given by the correlating SDE Rules. The abbreviations refer to the Team entries in each of the Competitions. Source: University of Wuppertal, Susanne Hendel




As the SDE is a Competition between Teams of students, the restrictions are created to ensure the feasibility of the building task. In order to ensure security and feasibility, the SDE houses have net floor areas between 42 m² and 74 m² (Figure 1.4) and in 2010 and 2012 most of the houses were one storey only. At the SDE14, as the maximum net flor area was extended up to 110 m², two storeys houses became common. The strict restrictions to the size of the buildings are, although because of limited space at the Competition site, the need for short construction times and, as mentioned above, adherence to safety aspects during construction.

The aim is to design and evaluate houses for a two-person household; if the above-mentioned areas are taken into consideration, this corresponds to an average floor area of 35 m² per person. In Europe in 2011, the average living area per person was about 43 m² [ec housing 2011], therefore, the use of the houses is considerably more dense.

Small buildings have more envelope area in relation to living space because of their unfavourable form factor. Figure 1.5 shows the surface to volume ratio, the so called form factor of exemplary SDE houses compared with two usual single family homes (SFH). The two SFH chosen here represent the common form factor of homes in European building practice. Both homes were part of a research project for energy efficient homes in Europe [voss 2011]. The form factor of SDE houses is usually twice as large as that of standard European homes. However, the very low form factors of the houses 2014 DEL and 2014 MEX are outstanding. These low values can be explained by the fact that in 2014 a two-storey construction and a building size up to 110 m2 net floor area was permitted. The two houses 2014 MEX and DEL with two floors were clearly more compact than the usual single-storey SDE houses. This increases the buildings costs per floor area; however, on the other hand it also increases the available area for solar systems in relation to the floor area.

solar
decathlon
europe

Figure 1.5: Form factor A/V of the SDE houses as listed by Teams. To compare the form factors of SDE houses to houses in European building practice, two exemplary single-family homes from a German energy efficiency research project are also listed here (SFH1, SFH2). Source: University of Wuppertal, Susanne Hendel

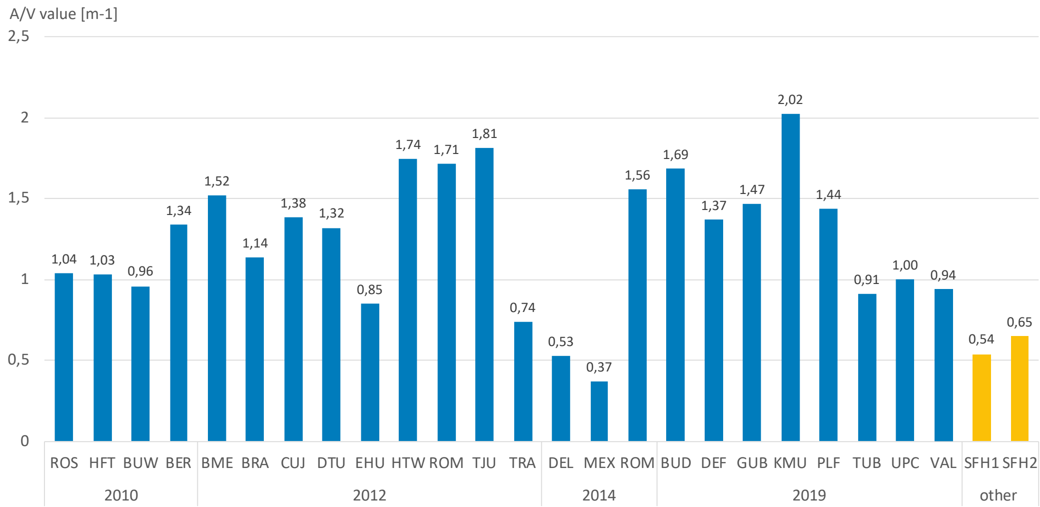



Figure 1.6: In order to create additional storage space in a small space, drawers are located under the stairs in the SDE10 BUW house. Source: SDE, Flickr, [sde flickr doc]

Figure 1.7: In the SDE10 BER house, all functions such as cooking, eating, living and sleeping have been combined in one room. Light bands in the walls and the roof symbolically separate the room into zones of use. Source: SDE, Flickr, [sde flickr doc]

Figure 1.8: As in the 2010 BUW house, the SDE12 RWT house also uses the construction areas for storage space. Here, cabinets and the kitchen are integrated into the walls. Source: SDE, Flickr, [sde flickr doc]

Besides the buildings' size, there are further restrictions with which the SDE houses need to comply. One of them is the so-called solar envelope. The solar envelope has the geometry of a square, truncated pyramid with a base area of 20x20 m, a height of 5.5 m and a roof area of 10x10 m [sde10 2010]. A maximum height of 6 m [sde12 2012] in SDE12 and 7 m [sde14 2014] in SDE14 were permitted. The solar envelope restrictions mainly guarantee unshaded location of the buildings on the Competition site in order to ensure fair Competition.

Taking into consideration the building's design and habitability, the Teams have to consider a space-efficient floor plan and building design. Space-efficient living concepts provide impulses for future living in European cities. Examples of space-efficiency are provided by the SDE10 Teams, Wuppertal (BUW) and Berlin Living Equia (BER) and the 2012 Counter Entropy (RWT). The Wuppertal and the Counter Entropy examples show that space can be used multifunctional as storage. In the Wuppertal house, even the space underneath the steps of the stairs is used. The RWT building integrated storage space within the walls. The BER house demonstrates an open-plan design. The use of every space for storage as well as the creation of an open floor plan to maximize habitability is common in the SDE.


Figure 1.6


Figure 1.7


Figure 1.8

solar
decathlon
europe

As the SDE houses lack an urban context, a number of experimental or extraordinary designs can be expected (Figures 1.9, 1.10). Besides the most common rectangular floor plan, the SDE houses demonstrate a wide range of floor plan designs. Even circular (UDZ in the SDE12) or freeform floor plans (IAA in the SDE10) are possible, due to the lack of a site, district or urban context. In European building practice and particularly in an urban environment it would be almost impossible to adopt these more experimental designs.



Figure 1.9: The 2010 Fablab House is an example for an experimental building shape. Source: SDE, Flickr, [sde flickr doc]

Figure 1.10: The building shape of the 2012 Unizar house shows a circular floor plan with lots of consequences for interior furnishings. Source: SDE, Flickr, [sde flickr doc]

However, apart from a few examples, the statistics show that many of the SDE houses follow a simple cubature in the tradition of the 'Bauhaus' movement of 100 years ago. Simple cubatures are at an economic advantage due to lower material use and construction time. Their presentation may also stimulate future European building practice.

A closer look at the design shows that most SDE houses have a rectangular floor plan. This is in contrast to the square or L-shaped floor plans more commonly used in Europe squared. Figure 1.11 depicts the floor and roof shapes of the SDE houses according to their frequency. Almost half of the houses have a rectangular floor plan; almost half of them have a flat roof. Together, they represent 30% of all the designs. Keeping in mind the above-mentioned solar envelope, its limited base and top shape and also the net floor area limitations, the Teams needed to find a way to squeeze in as much space and as many functions as possible. The simple shape of a flat roofed building with a rectangular floor plan seems to be a safe choice for the Teams.

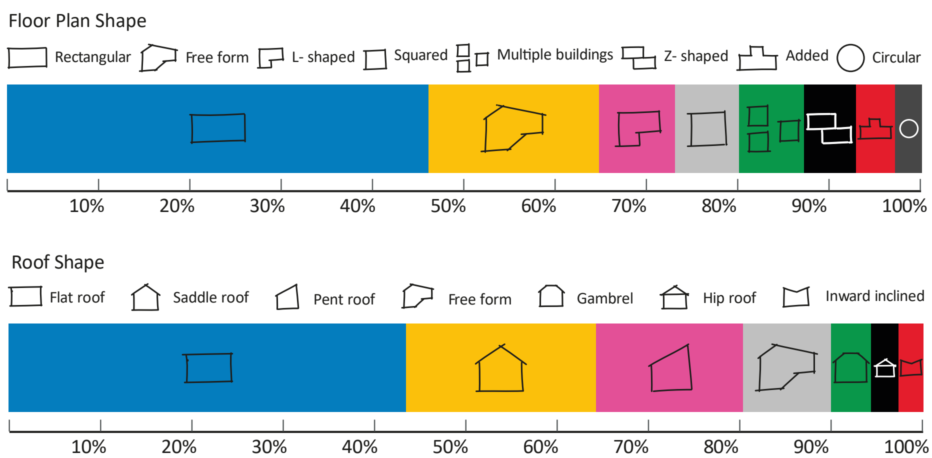



Figure 1.11: Floor plan shape and roof type of the SDE houses in SDE10, SDE12 and SDE14. Source: University of Wuppertal, Susanne Hendel

Alongside the flat roof, almost 20% of the houses had a saddle roof and about 15% had a shed roof. Flat roofs are predominant in the SDE and become more usual in building practice in Europe (new buildings) when no other roof shapes are stipulated by urban planning regulations.


Figure 1.12: The SDE12 winning Team Canopea (TRA) built a convincing example of the upper floor of an apartment building. Source: SDE Flickr [sde flickr doc]

Utilizing optimum alignment enables the roof pitches of saddle roofs and pent roofs to be utilized for building-integrated solar systems. The CUJ house in 2012 and ROM house in 2014 are vivid examples of this. On the other hand, flat roofs bear the potential of optimal alignment of the solar systems to the direction and angle of the sun; the alignment on a flat roof can even be flexible to ensure a maximum energy generation all year long. In real building practice, flat solar systems have the advantage of being less sensitive to building orientation.
In many cases, it is not possible to orient a sloped roof to the south. The SDE homes show both: solar systems were either elevated at an optimum angle and orientation (VGT 2010) or integrated flat on the roof (HFT 2010, AND 2012). Solar Systems are one of the most dominant design elements in the Solar Decathlon homes. In contrast to usual practice, many SDE roofs are utilized for solar systems covering the entire surface area. The direct consequence is that green roofs or any kind of vegetation on the roof is not frequently applied by SDE Teams.

The roof in the SDE is also a special element for interpretation. Some Teams did not build just a freestanding single-family home but interpreted the task to build an addition to an existing building. Teams like 2014 DEL, ROF and OTP are successful examples.
The Team DEL suggested a new exterior buffer zone to a standard Dutch single-family home.

solar
decathlon
europe

Small houses like the one presented by the DEL Teams are common buildings in the Netherlands which are in need of energy modernization and space extension (figure 1.28). The two German Teams ROF and OTP from SDE14 also focused on urban challenges. Both suggested a new additional storey on top of an existing multi-level building. Their concepts suggest an increase in urban density through the vertical extension of existing buildings. This is highly adoptable in practice.

In conclusion, the SDE houses significantly differ from houses which are common in European building practice. As the houses are built within a student Competition, they are significantly smaller and offer about 20% less living space per person, than is standard in the EU. The small size led to space-efficient housing concepts that can act as an inspiration, in particular for future urban living situations.

### 1.1.3 Architecture Scoring in the Competition

Architecture is one of the five core contests in the Competition.Scoring is always carried out by an expert jury; the architectural understanding of the respective jury members corresponds to that in any architectural Competition. The appropriateness of the architectural solution in order to fulfil the task chosen by the Team is at the heart of the evaluation. As there are considerable differences in the tasks chosen, evaluation and comparison are difficult.

When the scores of the architecture contest are compared, the Teams with the combined flat roof and rectangular floor plan solution were ranked in the first third. The most successful Teams who had decided to use this form were VGT (first place in SDE10), ROS (second place in SDE10) and HFT (third place in SDE10), ROM (third place in SDE12) and ROF (third place in SDE14). In particular, the entire formal language of these houses was simple, easily accessible, but individually designed. Especially in a Competition in which the jury only has a brief moment to evaluate the houses, a simple design language seems to be the most effective.

# 1.2 passive design

Passive approaches or passive technologies include all measures and design features to maintain or create a comfortable indoor climate without machines to generate heat or cooling from fuels or thermodynamic cycles. As stated in the SDE Rules [sde12 2012, p. 32], all technologies that rely on a thermodynamic cycle are considered active and the use of fossil fuels are prohibited (all electric homes). Ventilation fans or circulation pumps, which are a frequent example, are not considered active technologies. Passive approaches are priorities design strategies due to simplicity, user friendliness, durability and economic viability. Passive strategies often strongly interfere with architecture and therefor have to be considered in the early design.

Besides active solar energy utilization, SDE Competitions have always focused on the use of passive approaches and their positive effect on comfort, efficiency and energy usage [SDE14 2014, Para. passive period]. The so-called passive period was for the first time implemented in SDE12, and repeated in SDE14 and SDE19. Within this period of the Competition, no active HVAC technology is allowed to run, but comfort has to be kept. In SDE21 its Rules stipulate that, during the whole Competition, buildings may only be operated in the passive mode [eef 2019-1, Para. passive period].

As mentioned above, all SDE houses are light-weight constructions with a lack of thermal inertia. The SDE12 took place in September in Madrid and SDE14 in June/July in Versailles. The Teams of both Competitions had to deal with air temperatures above 30°C (Figure 1.13, 1.14). All Teams had to find concepts either to cool their building or at least prevent it from overheating. The green and yellow box in Figure 1.13 and 1.14 illustrates the comfort zones targeted by the Rules. If the room temperature and humidity is in the green box, then the conditions are considered comfortable and the Team would earn full points. For all measurements within the yellow box the Team would earn reduced points and for every measurement outside these boxes no points would be distributed. The comfort zones are a scoring tool during the whole Competition. During the passive period, only temperature comfort zones are in place [sde12 2012, Para. Appendix C: Passive Evaluation Periode]. To show the general discrepancies between the climate during the event and the expectations based on the Rules, temperature and humidity are both illustrated in Figure 1.13 and 1.14.

Figure 1.13: Annual weather data, including tempe¬rature and relative humidity of the SDE10 and SDE12 event site Madrid. The weather data (long-term average) were exported from the Meteonorm database. Also illustrated are the comfort range for room temperature and relative humidity set by the SDE Rules (boxes). Source: University of Wuppertal, Susanne Hendel

Figure 1.14: Annual weather data, including temperature and relative humidity of the SDE14 event site Paris. The weather data (long-term average) were exported from the Meteonorm database. Also illustrated are the comfort range for room temperature and relative humidity set by the SDE Rules (boxes). Source: University of Wuppertal, Susanne Hendel

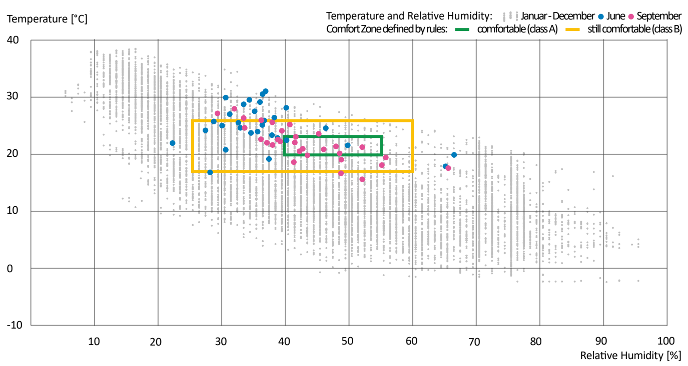



Figure 1.13

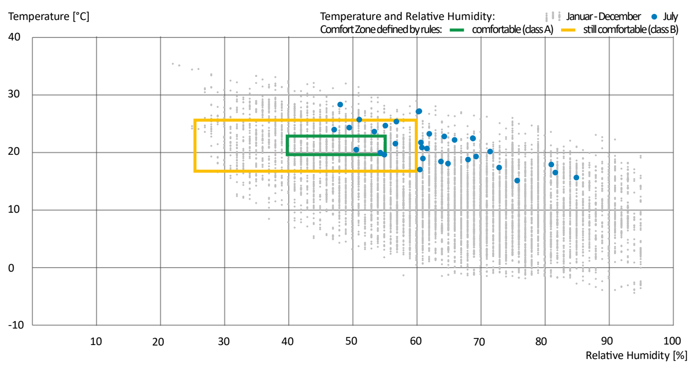



Figure 1.14

solar
decathlon
europe

### 1.2.1 Thermal Protection

Although the events take place in spring or autumn, SDE houses are designed for full year operation. This includes increased thermal protection to reduce the space heating demand as far as possible. Increased thermal protection is the major approach for energy saving, namely in the central and north European countries. The far majority of the Teams follow an approach with U-values of the opaque elements typical for low energy houses (≤0.2 W/m²) or even Passive houses (≤0.1 W/m²K). This corresponds to insulation thicknesses of 16 cm up to 35 cm. By the use of innovative materials with reduced thermal conductivity (IR radiation absorption, aerogel, vacuum insulation, etc.) Teams develop construction with reduced thicknesses. Most timber constructions are designed to minimize the timber fraction (TGI- beams, etc.) to avoid thermal bridges.

Glazing U-values below zero are often realized. This typically corresponds with the use of triple glazing, coated glass and inert gas filling. The increased weight of such glazing has to be taken into account carefully in the whole window and façade design. Some Teams show four-pane (SDE10 finish Team HUT - Luuku House) or innovative vacuum glazing in their houses (2012 Omoenashi House from the Japanese Team CUJ).

Testing the winter thermal protection was not a task in evaluation of the Competition monitoring data due to the relatively high ambient temperatures during the events. Transmission losses or gains become a second order effect under these circumstances and measurement errors would increase. The level of thermal protection was considered as part of the jury evaluation on energy efficiency.

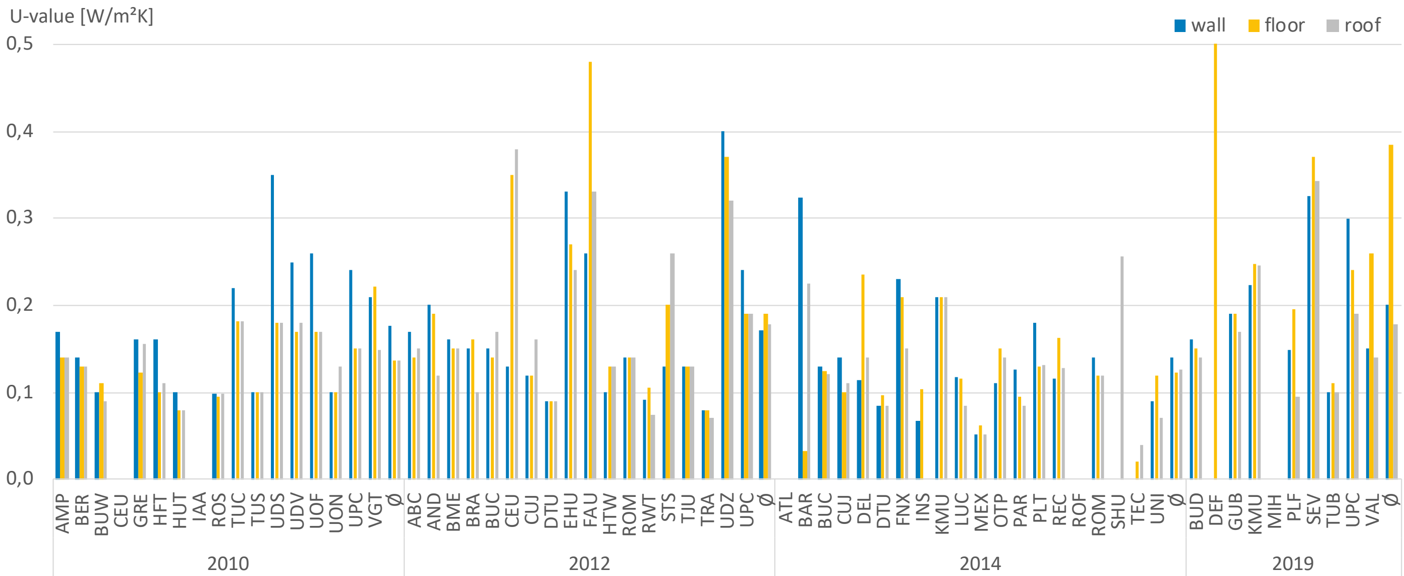



**Figure 1.15: Comparison of the thermal transmittance (U-value) of the main construction elements of SDE homes based on the date given with the construction manuals. Source: University Wuppertal**

solar
decathlon
europe

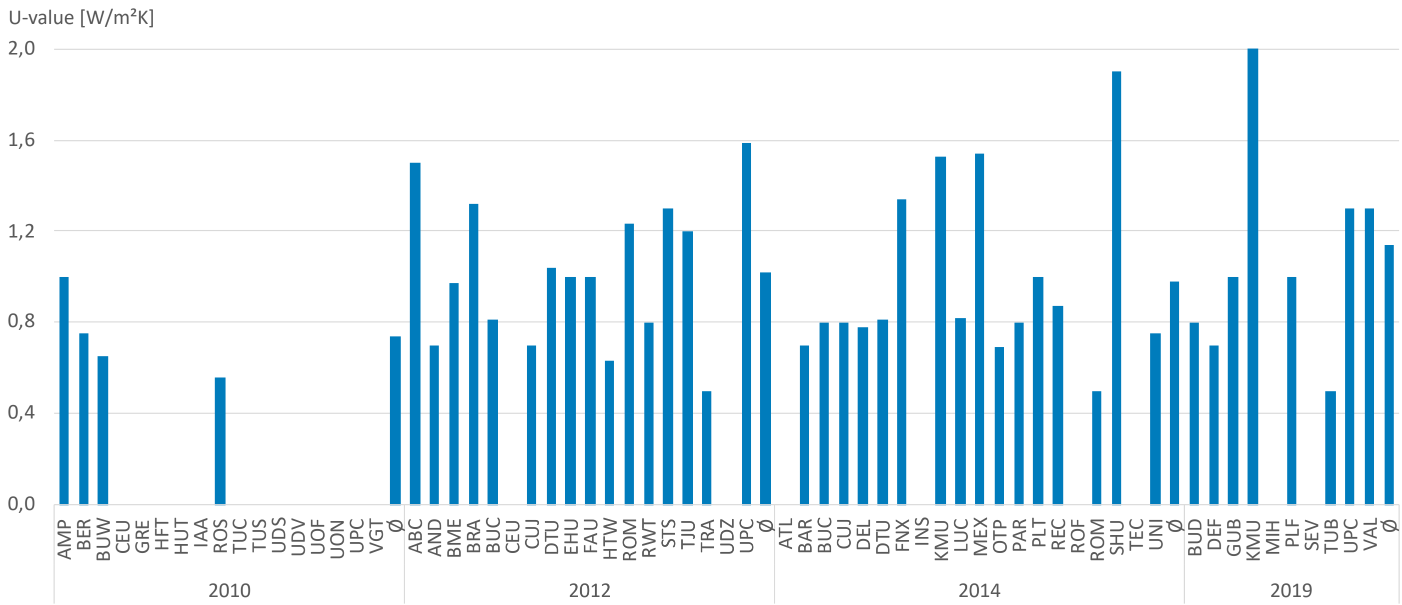



Figure 1.16: Comparison of the thermal transmittance (U-value) of the glazing applied in the SDE homes based on the date given with the construction manuals. Note: Whole window data including frame and spacers are not available. Source: University Wuppertal

Figure 1.17: Four-pane glazing at the SDE10 finish house (HUT - Luuku House). Source: University of Wuppertal, Karsten Voss

Figure 1.18: Vacuum glazing at the 2012 Omoenashi House from the Japanese Team CUJ. The vacuum double-glazing is combined here with a third pane to a triple glazing unit. Source: University of Wuppertal, Karsten Voss

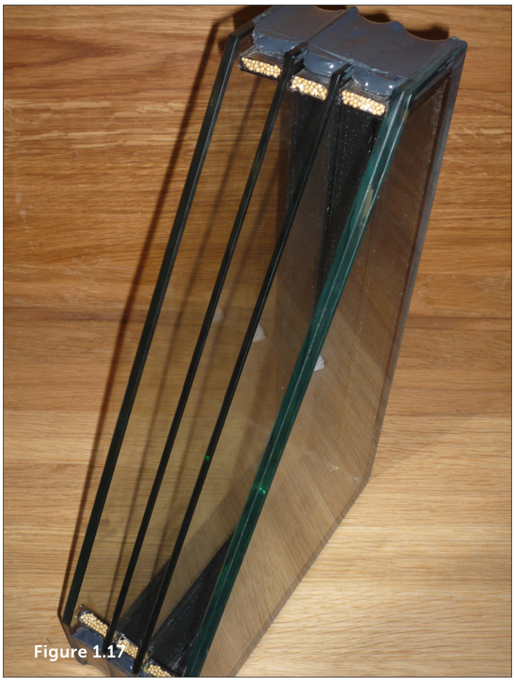


Figure 1.17


Figure 1.18

### 1.2.2 Windows and Shading

The proportion of window area in SDE houses is significantly higher than in common residential houses [voss 2011]. For example, the four German Teams in SDE10 designed their houses with a window to envelope area ratio between 10% and 25% [detail 2011]. This corresponds to a window to floor area ratio of 40%. The higher proportion of windows is due to the small size of the SDE houses. Window sizes cannot be scaled down according to the floor area scaling without significant comfort and design losses. Many SDE houses pursue concepts with particularly large window areas. Larger openings visually connect interior and exterior spaces. This connection allows small interiors to appear more spacious (2010 BUW, Figure 1.19).

As the SDE houses have more window area per floor area and less thermal inertia compared to common buildings [detail 2011, p. 154], they run greater risk of overheating. The Competitions took place in summer with moderate to high outside temperatures and solar irradiation with strict requirements for the indoor climate conditions. This situation made structural measures for overheating protection necessary in order to avoid large cooling loads.
Efficient solar gain control through the application of any type of shading was crucial and carried out by all SDE Teams. Solar gain control is currently of increasing importance in many European locations due to rising summer temperatures and lengthier hot periods as a result of global climate change. Demonstrating and testing effective and attractive shading in the Competition entries can thus stimulate the market and raise public awareness.

Considering not only the location of the shading installed but also the way it works, several types of sun protection can be distinguished here. The general approaches are split up into a large variety of fixed or moveable systems (Table 1.1). Fixed systems such as the use of solar control glazing or overhangs (2010 HFT, 2012 RWT, 2014 ROM) operate without user interaction, thus, making solar protection secure. On the other hand, passive solar energy utilization is more (solar control glass) or less (overhang) reduced which results in increasing space-heating demands. External sun protection comprised moveable shading systems such as venetian blinds or screens (2010 VGT, 2010 BER, 2014 ROF) or curtains (2010 BUW, 2012 RWT). Moveable systems rely on building automation systems and/or operation by the user. Advanced automation systems might take into account weather forecasts and the adaptive learning of room utilization profiles.
No limiting of passive solar gains in the heating season is the advantage of moveable devices.

The most effective systems are external devices such as venetian blinds, screens or shutters. They may block solar gains by 90% but at the same time, they block most of the view, depending on their positioning.

Interior shading, for example by curtains, is much less effective (about 35%). Therefore, it comes as no surprise that external sun protection was applied by all SDE Teams, but with a wide variety of system solutions. Only very few Teams used rolling shutters, mainly because of their poor reputation among architects. Still, these are the most popular products in European residential building practice for reasons of noise protection, security and cost. From this point of view, the SDE homes are well suited to showcase advanced solar shading designs.

solar
decathlon
europe

Figure 1.19: Windows are used to visually connect the small interior living space to the exterior. This way small interior spaces appear more spacious. Exemplary picture of the SDE10 Wuppertal (BUW) house. Source: Amparo Garrido

Table 1.1: Type of shading applied in SDE homes. The statistic is based on the Team's deliverables and viewing of the house pictures. Shading systems here are divided into exterior and interior elements. The exterior elements are further distinguished into fixed elements like overhang or façade elements, that are built in front of windows or openings. Some Teams apply PV modules as part of the shading devices. Source: University of Wuppertal, Susanne Hendel

| Year | Team | Exterior shading | | | | Interior shading | Shaded roof |
|---|---|---|---|---|---|---|---|
| | | Overhang | Fixed external | Moveable external | Added value | Moveable vertical | |
| 2010 | VGT | | | Sliding shutter | | | |
| | ROS | X | | X | | Curtain | X |
| | HFT | X | | Curtain | | | |
| | GRE | X | | X | Solar system | Curtain | |
| | HUT | X | Wooden elements | | | | |
| | BUW | | | Curtain | | | |
| | AMP | X | | | | | |
| | UOF | X | | Shutter | X | | |
| | CEU | X | Façade elements | Curtain | | Curtain | |
| | BER | | | X | Solar system | | |
| | UDS | X | | Venetian blinds | | | X |
| | TUS | X | | Venetian blinds | | Moveable vertical | |
| | UPC | X | | Sliding shutter | | | |
| | UDV | | | | | | |
| | UON | X | Façade elements | | | | |
| | IAA | X | | | | | |
| | TUC | X | | Shutter | | | |

solar decathlon europe

| Year | Team | Exterior shading | | | | Interior shading | Shaded roof |
|---|---|---|---|---|---|---|---|
| | | Overhang | Fixed external | Moveable external | Added value | Moveable vertical | |
| 2012 | TRA | | Glazing integrated PV | Glazing integrated venetian blinds | | | X |
| | AND | X | Façade & roof elements to shade patio | | | | |
| | ROM | X | | | | | |
| | HTW | X | | Curtain | | | |
| | RWT | X | | Curtain | | | |
| | BME | | | Awning | | | |
| | CEU | X | Façade elements | | | | |
| | UPC | | | Curtain | | | |
| | BUC | X | | Shutter | | | |
| | DTU | X | | | | | |
| | TJU | X | Fixed wooden structure | | | | X |
| | ABC | X | | Doors | Solar system | | X |
| | BRA | X | | Venetian blinds | | | X |
| | EHU | X | | Slides | | | |
| | CUJ | X | | Venetian blinds, sliding shutter | | | |
| | FAU | X | Fixed structure with PV | Doors | Solar system | | X |
| | UDZ | X | | | | | X |
| | STS | X | | Shutter | | | |
| 2014 | ROM | X | | Sliding shutter | Solar system | | |
| | DEL | X | Glazing integrated PV | | Solar system | Moveable vertical | |
| | ROF | X | | Shutter | Solar system | Curtain | |
| | DTU | X | Façade elements | | | | |
| | LUC | | | | | Curtain | X |
| | FNX | X | | Venetian Blinds | | | |
| | OTP | X | | | | | |
| | BAR | X | | | | | |
| | CUJ | X | | | | | |
| | UNI | | Glazing integrated PV | Sliding shutter | Solar system | | X |
| | REC | X | | | | | |
| | MEX | X | | Curtain | | | |
| | INS | X | | | | | |
| | PLT | X | | | | | |
| | TEC | X | Façade elements | | | | |
| | KMU | X | Façade elements | Venetian blinds | | | |
| | SHU | X | | | | Moveable vertical | X |
| | BUC | X | | | | | |
| | PAR | X | Façade elements | | | | |
| | ATL | | | | | Curtain | |

solar
decathlon
europe

| Year | Team | Exterior shading | | | | Interior shading | Shaded roof |
|---|---|---|---|---|---|---|---|
| | | Overhang | Fixed external | Moveable external | Added value | Moveable vertical | |
| 2019 | BUD | X | | | | Blinds | |
| | DEF | X | | Rolling system | | | X |
| | GUB | X | | Shutter | | | X |
| | KMU | X | | | | | X |
| | MIH | X | | | | | |
| | PLF | X | | | | Curtain | |
| | TUB | X | | | | Curtain | |
| | UPC | X | | Shutter | | Curtain | |
| | VAL | X | | Slats | | | |


**Figure 1.20: Distribution of external, internal, fixed and moveable sun protection devices presented by the SDE houses. Source: University of Wuppertal, Susanne Hendel**

Combinations of more than one shading system were also common in the SDE. External and internal shading devices were combined by 30% of the SDE10 Teams, by 35% of the SDE12 Teams and 45% of the SDE14 Teams. In building practice, the combination of external and internal shading in the south of Europe is quite common, even necessary, while in central and northern Europe it is uncommon. The high relevance in the Competition is due to the higher room climate requirements for SDE houses compared to the practical requirements for residential buildings.

solar
decathlon
europe

The shading concepts presented in the SDE can provide valuable input for building practice. Effective use of shading significantly improves the building performance during the hotter months. In Central and Northern European building practice, the boost to performance would be recognized as a gain in comfort and generally not seen as an energy-saving gain because active cooling is not common in residential buildings Active cooling is quite common in Southern Europe, especially in hot humid climate; shading systems are always used in residential buildings. The focus on efficient shading is an important contribution to make the students and the visitors of the Competition aware of the increasing role of summer thermal comfort considering the effects if climate change in Europe with increased ambient temperatures and longer hot periods.

Apart from their effectiveness, shading elements are dominant design elements in the SDE houses. More than standard buildings, the SDE buildings are dominated by them due to their large window areas. Many of the shading ideas presented cannot be adopted by the building practice mainly due to the existing contexts and restrictions to which standard buildings have to adhere. However, with their design focus, some ideas certainly have the potential to inspire building professionals. Figures 1.21 to 1.26 depict a few such examples.

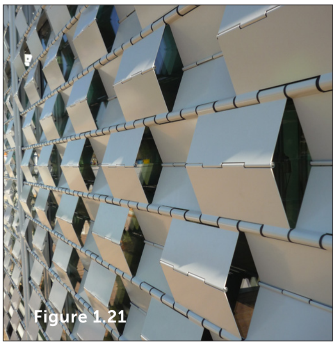





Figure 1.21: Moveable aluminum sun screen at the SDE10 ROS house. The profiles are specially folded to avoid direct light transmittance. The system as a whole is moveable from the bottom to the top and stored at the bottom of the façade. Source: University of Wuppertal, Karsten Voss

Figure 1.22: View through an external curtain as a moveable sun protection device presented by the SDE10 Wuppertal house (BUW). A transparency of 7% is sufficient for visual contact. Source: University of Wuppertal, Karsten Voss

Figure 1.23: Moveable vertical and external sun protection additionally used for solar power generation presented by the SDE14 ROM house.
Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

solar
decathlon
europe

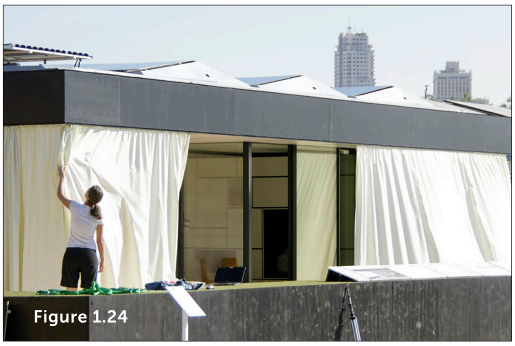


Figure 1.24


Figure 1.25


Figure 1.26

Figure 1.24: Overhang combine with external curtains at the 21 RWT house. Source: SDE, Flickr [sde flickr doc]

Figure 1.25 Fixed shading with integrated PV application and planting at the house of the Team TJU at SDE12. Source: K. Voss, University Wuppertal

Figure 1.26: Foldable external sun protection additionally used for solar power generation at the 14 ROF house. Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

### 1.2.3 Buffer Zones

Buffer zones integrated into the floor plan enable the fully conditioned volume of a building and thereby the energy demand to be reduced. On the other hand, indoor thermal comfort of these spaces will be temporarily outside the comfort range during very cold or hot periods of the year, resulting in reduced utilization options. These limited utilization times have to be communicated to the occupants in order to avoid their misuse by fully heating or cooling such spaces with additional, mobile HVAC systems or by opening doors to the connected, fully conditioned rooms.

Buffer zones can be fully interior (interior buffer zone) like in an atrium house, fully attached (exterior buffer zone) such as a conservatory or a space within the construction layer like a ventilated façade (shell/ façade). Buffer zones may also serve as the upper or lower part of an apartment building to host communal spaces or allow for communal activities.

The variety of examples results from the different cultural background of the Teams participating in the SDE. There are participating Teams from countries with a long tradition in using buffer zones in architecture. The large variety of the approaches and designs presented raises public awareness of the use of non-conditioned and partially shared spaces for residential applications.

Special designs address building refurbishment. Typical market examples are post-war terraced houses with small living areas where a conservatory extends the space available during certain times of the year. Other examples are glazed balconies to reduce the thermal bridges in post-war apartment buildings with insufficiently insulated balcony ceilings.

The thermal insulation of a buffer zone envelope is typically less ambitious. This allows the use of ‘low-cost’ materials or constructions such as greenhouses. Therefore, the building costs per volume are generally lower for buildings using buffer zones than for conventional buildings of the same total volume. Active solar systems might be integrated more easily in the buffer zone envelope than in the main building envelope as the requirements of thermal or sound insulation which have to be met are less strict. One such example is glazing integrated photovoltaics.

solar
decathlon
europe

Buffer zones can be an integrated part of a building's ventilation concept in order to increase the comfort of the nearby zones. In winter, the zones may preheat the incoming air to the building by passive solar energy utilization. A typical solution is a conservatory (SFH) or a glazed balcony (MFH). Also, the zones may work as a solar chimney to increase stack effect ventilation for better summer thermal comfort. A special form of a buffer zone is the air gap in a ventilated façade construction, which may work to preheat the entering air or increase the ventilation by stack effect.

In the SDE context, buffer zones are well represented. Often, they are a credit to the vernacular architecture of the Team's region of origin. Some Teams develop new interpretations especially in interaction with active solar energy harvesting. Figure 1.27 gives an overview of the basic forms of the buffer zone buildings detected in SDE10 to SDE19. Table 1.2 lists the special functions of these buffer zone concepts for advanced low energy houses and their innovations.
Selected examples from this table have been extracted with pictures to highlight the most innovative approaches. Innovations may cover

- special market segments such as apartment buildings or the refurbishment sector,
- advanced functionality in the building's energy concept such as ventilation or solar system integration,
- special materials such as functional textiles, or
- added value of the space.

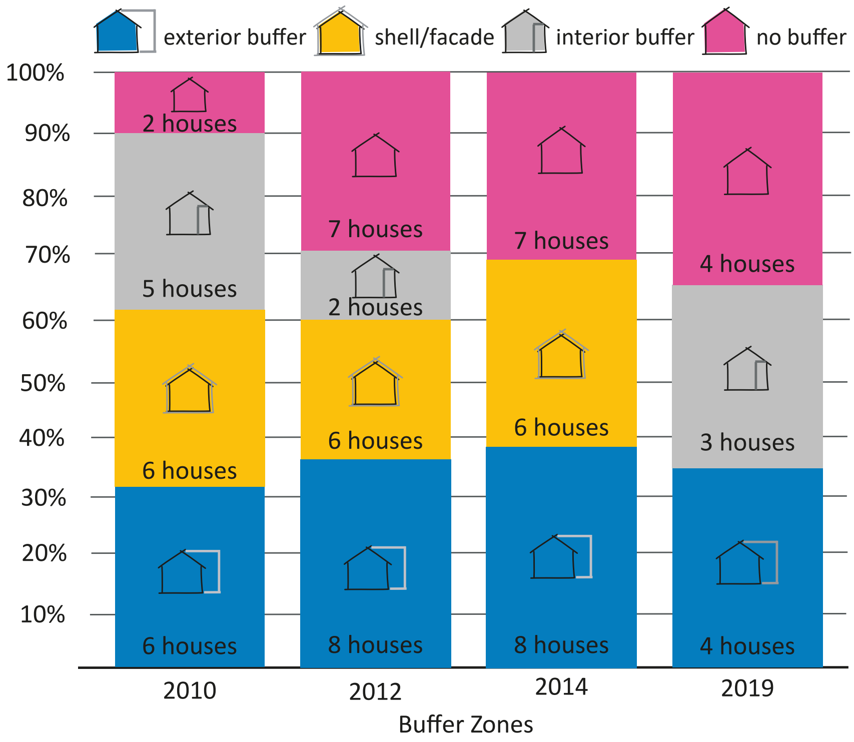



Figure 1.27: Number and type of buffer zones in past SDE Competitions. The figure illustrates the frequency of the different type of buffer zones applied in and at the SDE houses. Buffer zones are distinguished here into exterior and interior buffers and buffer facades. Source: University of Wuppertal, Susanne Hendel

solar
decathlon
europe

Table 1.2: Overview of the types of buffer zone applied in SDE Competitions 2010 to 2019.

Source: S. Hendel, University Wuppertal

| Year | Team | Building type | | Building size | | Design Features & Innovations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | New | Refurbished | Single family | Apartment building | Ventilation Integration | Buffer Facade | Active Solar | Material Innovations | Added value |
| 2010 | VGT | X | | X | | X | X | | | |
| | ROS | X | | X | | | X | | | |
| | HFT | X | | X | | X | | | | |
| | GRE | X | | X | | | | PV | | |
| | AMP | X | | X | | | X | | | |
| | UOF | X | | X | | | X | | | |
| | TUS | X | | X | | | | | | |
| | UPC | X | | X | | | | PV | Translucent façade | Foyer, Communal space |
| | UON | X | | X | | X | | | | |
| 2012 | TRA | X | | | X | X | | PV | | Communal space |
| | AND | X | | X | | | | | | Patio |
| | ROM | X | | X | | | | PV | | |
| | BME | X | | X | | X | X | | | |
| | CEU | X | | X | | X | X | PV | | |
| | UPC | X | | X | | | | PV | Translucent façade | Foyer, Communal space |
| | EHU | X | | X | | | X | | | |
| | CUJ | X | | X | | | X | | | |
| | BRA | | | X | | | X | | | |
| 2014 | ROM | X | | | X | | X | PV | | |
| | DEL | | X | X | | X | | PV | | |
| | ATL | X | | | X | | | PV | Glass house | Stairwell |
| | LUC | X | | | X | X | | | | Foyer |
| | FNX | X | | X | | | | | Exterior curtain | |
| | OTP | X | | | X | | | | | Terrace |
| | DTU | X | | X | | | | PV | Glass house | Conservatory |
| | BAR | X | | X | | X | X | | Translucent façade | Façade as solar chimney |
| | UNI | X | | | X | X | | PV | | Stairwell |
| | MEX | X | | X | | | X | | Curtain | Communal space, ventilated façade |
| | PLT | X | | X | | X | | | | Multi-functional space |

solar
decathlon
europe

| Year | Team | Building type | | Building size | | Design Features & Innovations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | New | Refurbished | Single family | Apartment building | Ventilation Integration | Buffer Facade | Active Solar | Material Innovations | Added value |
| 2019 | BUD | | X | X | | X | | | Gabion wall | Conservatory |
| | DEF | | X | | X | X | | | | Conservatory, Communal space |
| | MIH | | X | X | | X | | | | Conservatory |
| | PLF | | X | X | | | | | Interior curtain | Stairwell |
| | UPC | X | | | | | | | Curtain | Terrace |
| | VAL | X | | X | | | | | | Terrace |

Figure 1.28: The attached conservatory at the 2014 DEL house with integrated solar systems demonstrates a buffer zone example for building renovation. Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

This example addresses the refurbishment of a typical post war Dutch terraced house. The new conservatory adds additional space to the typically small house and also creates the option of fully integrating active solar systems. The conservatory also takes part in the building's ventilation in order to reduce the energy demand of the house. The approach shows large national market viability because of the multitude of comparable situations in the Netherlands.

Other outstanding examples for exterior buffer zones are the 2012 AND (Figure 1.29) and 2014 UNI houses (Figure 1.30). The 2012 AND house illustrated a different approach. The total conditioned volume of the house is separated into four zones. These zones are connected by a patio that is protected against precipitation but open to the environment for ventilation purposes.

The conditioned zones are ventilated over the patio and profit in summer from the usually cooler air that passes through the patio. The patio is usually cooler than the environment due to the efficient shading and evaporative cooling combined with the natural ventilation which is in place. An exterior buffer zone was added to the UNI home. The building service equipment, the community spaces and a laundry area are located in this zone. On the roof of this buffer zone, photovoltaic modules are fully integrated into the envelope. This space enlarges the total footprint of the building but because it contains necessary functions and is not conditioned but just ventilated, it reduces the conditioned volume of the building.



Figure 1.29: Exterior buffer conservatory at the 2012 AND house, with advanced functionality for the building ventilation concept. Source: SDE, Flickr, Jose Luis Castillo [sde flickr doc]

Figure 1.30: Exterior buffer conservatory at the 2014 UNI house, with advanced functionality. Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

Separated from the unheated staircase. In addition, a temporary division of the bedrooms into a heated study and a cool sleeping area lead to a functional gain. Problems have to be considered with respect to moisture transport from the warm to the cold sections and the associated dew point shortfall.

Figure 1.31: A curtain to temporarily create a buffer zone in the SDE19 PLF house. Source: University of Wuppertal, Karsten Voss

Curtains were not generally applied as external separation of buffer zones. The 2012 RWT and 2012 HTW Teams used curtains to separate terraces directly adjacent to the building from their surroundings. The curtains protect these areas from high solar gains. These separated areas are nevertheless well ventilated thus protecting the rooms located behind them from overheating.

Translucent facade elements as demonstrated with the 2010 UPC house create a shell that surrounds the internal conditioned zones (Figure 1.32). The external shell of the building is based on low-budget materials and constructions such as greenhouses. This shell combines precipitation protection, solar protection and active solar energy utilization. The house is still in operation as a teaching and research facility in the form of a living lab [living lab 2019] at the campus of the Catalonia Polytechnic. A comparable concept with the aim of direct market stimulation was demonstrated by the Cubity house as an out of contest project in SDE14 [cubity 2014]. Today, the Cubity prototype is used as a student dorm in Frankfurt, Germany, generating regular rental income.

The Canopea house at the SDE12 of the Team Rhone-Alpes (2012 TRA) shows the top floor of an apartment building as a buffer zone. The project (Figures 1.33, 1.34) demonstrates the tenth floor apartment plus the buffer zone on top with its collective functions for the whole building.

solar
decathlon
europe

Photovoltaic modules are integrated into the entire roof surface of the glass roof of the buffer zone. These modules occupy a total area of 84 $m^2$ with nominal output of 8.7 kW. The other benefit of the buffer zone is its function as communal space which is of benefit to all residents of the house.

This type of communal space is also tested by the Cubity project (Figure 1.35, 1.36). The Cubity project is based on a SDE14 connected development; the Cubity did not compete in the SDE but was a side project of the SDE14, which was presented out of Competition at the SDE site in Versailles. Cubity demonstrates a house with minimal living space per inhabitant (7.2 m2), shared spaces located in an unconditioned buffer zone, translucent façade and internal space separation with curtains. In Cubity the students share a kitchen, dining areas and lounge areas located in the buffer zone of the house. With respect to market stimulation, the Cubity project shows a promising development. The success of the Cubity project and especially the shared spaces concept led to a follow-up project the so called Founder Lab [dstadt 2019], opened as a shared-space office building for young entrepreneurs. This type of development is a stimulating example for a direct market uptake from Solar Decathlon Europe.

Figure 1.32: A meeting house for a local district with a translucent façade at the SDE10 UPC house. The construction is based on typical greenhouse elements such as multilayer polycarbonate plates. Source: SDE, Flickr [sde flickr doc]

Figure 1.33

Figure 1.33: Exterior view of the Canopea house of the French 2012 TRA Team. The unit demonstrated the upper floor with an additional buffer zone on top of an urban apartment building.
Source: SDE, Flickr [sde flickr doc]

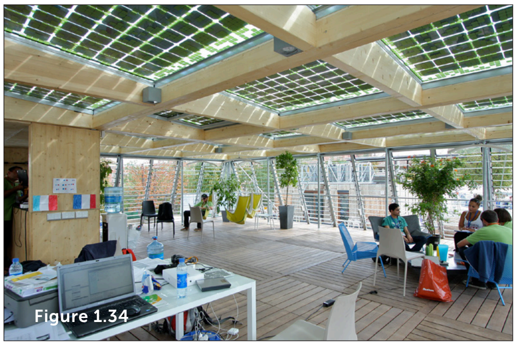


Figure 1.34

Figure 1.34: Interior view of the 2012 TRA buffer zone. The roof integrates PV modules for solar power generation.
Source: SDE, Flickr [sde flickr doc]

Figure 1.35

Figure 1.35: Exterior view of the Cubity house at its most recent location in Frankfurt.
Source: University of Wuppertal, Victoria Kunz

Figure 1.36

Figure 1.36: Interior view of the Cubity house. The image shows the communal kitchen which is located in the buffer zone of this house.
Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

### 1.2.4 Passive Ventilation

In about 20% of the houses, there are designs and constructions for enhanced passive ventilation. Physically, the driving forces for passive ventilation are either temperature differences or pressure differences on the building envelope resulting from the wind. As the SDE homes only have one or two storeys they are generally not high enough to catch the wind. Pressure differences have to be increased by special designs such as solar chimneys.

The advantage of passive ventilation is in avoiding electricity consumption for the use of fans; the disadvantage of it lies in the complexity of the design and the controls. Designs such as solar chimneys or wind catchers become visible features of the architectural language. The automatic activation of openings to control the air flow creates the need for indoor and outdoor climate monitoring, rain guards and other features.

Passive ventilation is predominantly designed for moderate and warm climatic conditions and to prevent summer overheating and induce night ventilation by making use of the nighttime ambient temperature drop. In cold climates, the need for ventilation heat recovery during winter favours fan-assisted solutions. Heat recovery can hardly be achieved with passive systems.
The increased interest and market relevance of passive ventilation for summer thermal comfort may come about as a result of climate change in central European countries with rising temperatures and longer hot periods. They adopt approaches which have their origins in the architecture of southern regions. If a Competition takes place in a hot climatic region, ventilation towers and solar chimneys play a bigger role than in Europe. One example of this is the Solar Decathlon Middle East in Dubai, 2018, or in Morocco 2019.

solar decathlon europe

Table 1.3: Overview of the types of passive ventilation approaches applied in SDE Competitions 2010 to 2019. Source: University Wuppertal

| Year | Team | Passive ventilation by | | |
|---|---|---|---|---|
| | | Stack/Chimney effect | Venturi effect | Visible architecture element |
| 2010 | HFT | X | X | Solar chimney |
| | BUW | X | | |
| | GRE | | X | |
| | TUC | X | | |
| | UDS | X | | Solar chimney |
| | UON | X | | |
| 2012 | AND | X | | |
| | ROM | X | | |
| | UPC | X | | |
| | ABC | X | X | Solar chimney + roof element |
| 2014 | DEL | X | | |
| | LUC | X | | |
| 2019 | MIH | X | X | Solar chimney + roof element |

Solar chimneys are a typical architectural element for making use of solar energy to power passive ventilations during day and night. The 2010 BUW, 2012 AND, 2014 DEL and 2014 LUC Teams also utilized the stack effect for passive ventilation, but unlike the HFT solar chimney, these are not perceivable as construction technology and only use the given temperature differences in the houses. Examples of solar chimneys which shape the architecture of the house can be seen in the houses SDE10 HFT (Figure 1.37) and UDS (Figure 1.38).

The SDE houses have a low maximum height of less than 7 m [sde10 2010, Para. Solar Envelope]. The low height leads to low wind effects. Nevertheless, some of the buildings use visible elements to deliberately accelerate the air flow when the wind blows to create a vacuum for the building's ventilation (Venturi effect). Such elements were presented for example by the houses SDE12 Symbiosis (ABC) and 2019 Someshine (MIH) (Figure 1.39, 1.40).

A detailed investigation of the benefits of passive night ventilation on the thermal performance of the Competition buildings is not possible based on the monitoring data available. Measurements of the interior room temperatures during the so-called passive period are available for the SDE12 houses (Figure 1.41). These give an impression of the sum of all measures taken as no heating or cooling devices were used during this period. However, the available data does not enable an evaluation based on individual measures to be carried out. Figure 1.41 depicts the temperature curves of all SDE12 houses. The curves of the houses AND, EHU and HTW are highlighted in bold together with their trend lines as examples for potential differences.

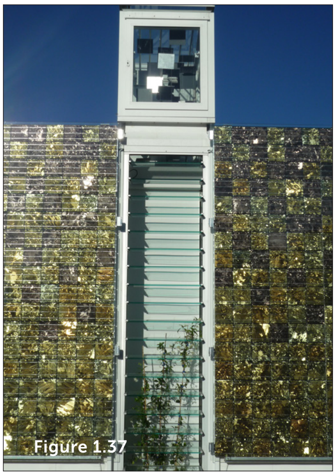
solar
decathlon
europe

Figure 1.37: Solar chimney as part of the SDE10 HFT house. Source: University Wuppertal, Karsten Voss

Figure 1.38: Solar chimney at the SDE10 UDS house. Source: SDE, Flickr [sde flickr doc]

Figure 1.39: Roof construction with a Venturi wind catcher on the SDE12 Symbiosis house (ABC). Source: SDE, Flickr [sde flickr doc]

Figure 1.40: Roof construction of the SDE19 MIH house to use the Venturi- effect in addition to a solar chimney for passive ventilation. Source: University Wuppertal, Karsten Voss







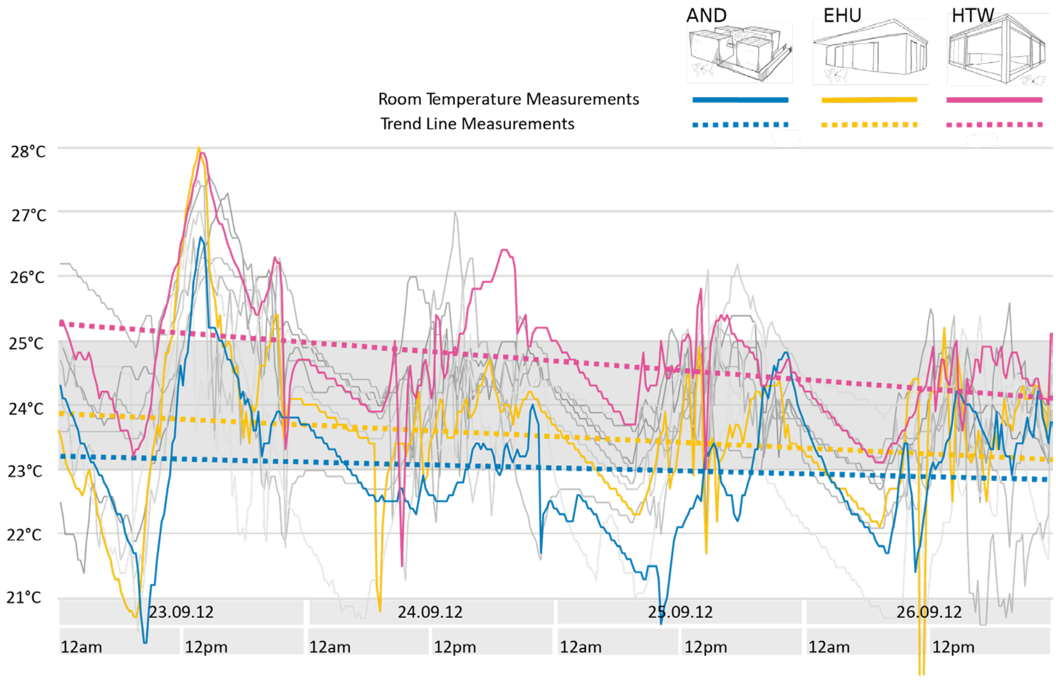



Figure 1.41: Comparison of the measured indoor air temperatures during the so-called passive period of all houses in SDE12. The curves for the three Teams AND, EHU and HTW are highlighted with bold lines and added trend lines. The comfort range for full points is indicated by the grey field between 23°C and 25°C. Source: University of Wuppertal, Susanne Hendel

solar
decathlon
europe

As depicted in Figure 1.41, all SDE12 houses manage to keep their interior room temperature mainly within the range defined as comfortable by the SDE12 regulations (full points) which lies between 23°C und 25°C [sde12 2012, Paras. 19, 5.1 Temperature]. The temperature level differs by up to 2° K between the houses which can also be seen in the starting condition at the beginning of the graphic. Special mention is made here of the 2012 AND house as it reached the lowest room temperatures on average. The 2010 HFT house which had on average the highest room temperatures had temperatures which were 2° K above those of the AND house. The temperatures of the EHU house lay in the middle between them. Especially the AND and HFT houses have significant differences in their use of passive strategies; the AND Team combined fixed and mobile external shading with a central and passively ventilated buffer zone which is additionally cooled by evaporation. All living spaces border the buffer zone and were ventilated by them during the 'passive period'. The AND Team concept was especially honoured by the energy efficiency jury. The HTW Team, which had the largest temperature difference to the AND Team, only focused on the use of shade in their passive concept; the HTW house combined an overhang with external curtains.

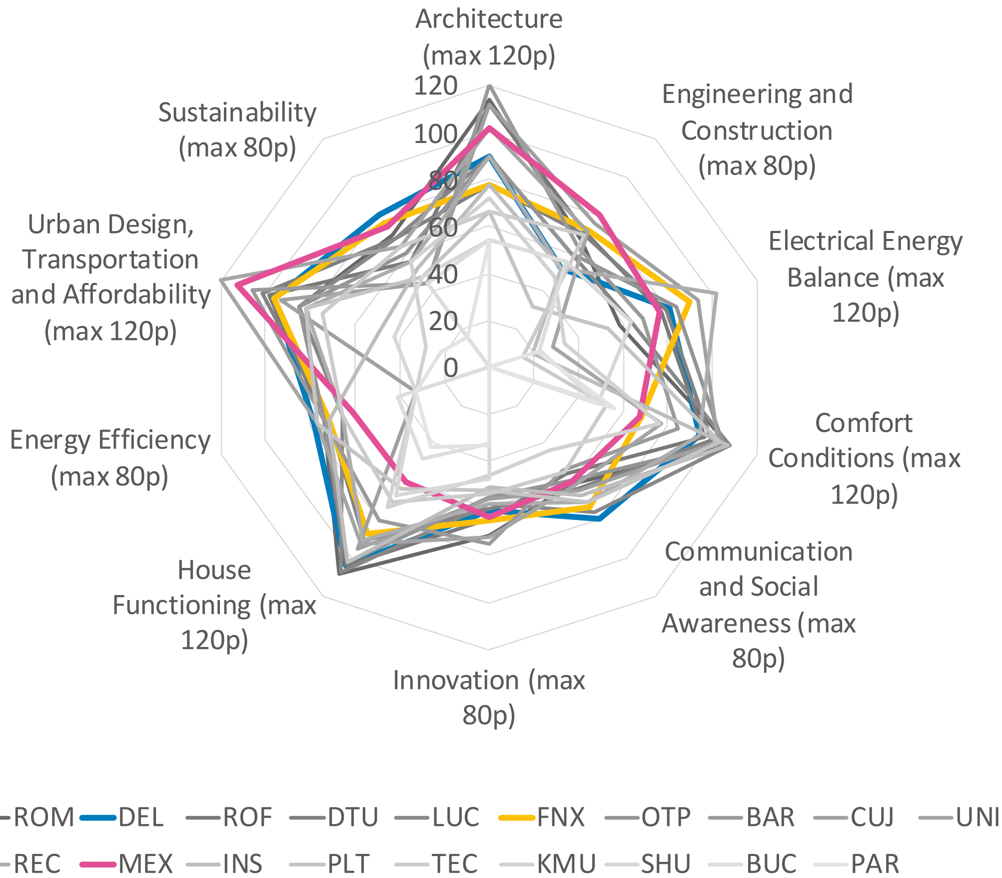
**Table 1.4: Key data on the interior temperatures in the selected houses (from Figure 1.41) AND, EHU and HTW. The temperature limits for the comfort zone for interior room temperatures of between 23°C and 25°C complies with the specifications of the Competition regulations. At the SDE, the Teams won full points for temperatures within this zone. For temperatures between 21 – 23°C and 25 – 28°C less points were awarded.**

| Team | Lowest Temp | Temp below 22°C | Temp below 23°C | Temp. above 25°C | Temp. above 26°C | Highest Temp |
|---|---|---|---|---|---|---|
| AND | 20.3 °C | 13% | 48% | 3% | | 26.6 °C |
| EHU | 20.3 °C | | 23% | 6% | | 28 °C |
| HTW | 21.5 °C | | 1% | 27% | 9% | 27.9 °C |

The potential of passive technologies for increasing building efficiency was examined by the energy efficiency jury. When they judged the houses the jury had no information on the performance data as depicted in Figure 1.41. Thus, the award of points in the contest 'energy efficiency' as an evaluation basis for the passive design is an independent addition to the comfort measurements. The purpose of this was for the contest 'energy efficiency' to not only take into consideration passive systems but also active systems, the efficiency of the building envelope, the household appliances, the annual energy demand and the efficiency of the regulation strategies. Apart from the award of points, there is no other documentation of this contest.

solar decathlon europe

Figure 1.42: Spy diagram of the scoring of all contests and all Teams in the SDE12. The three Teams discussed above are highlighted. Please note that the contests don't have the same maximum points. 100 points were the maximum result for energy efficiency contest and given to the AND Team.
Source: University of Wuppertal, Susanne Hendel




Some Teams, such as the AND Team from the University Seville at SDE12 have deeply investigated the thermal performance of the ventilation for example by computational fluid dynamic simulations [terrados 2014]. It is a kind of disadvantage of passive ventilation approaches that the numerical investigation as part of the design phase becomes much more complex compared to fan based ventilation. Therefor planning is often based on 'rules of thumb' and fans assist the ventilation as a kind of back-up approach in the case that strict indoor comfort requirements have to be kept.

### 1.2.5 Further Approaches

In the broadest sense, passive strategies and technologies can be understood as the optimization of the indoor environment without running heating or cooling devices. Plants, green spaces, water basins and evaporative cooling were implemented in the majority of SDE houses to make the microclimate around the building more comfortable. Water evaporation by ponds or plants lower temperature while increasing humidity. The application is suitable as long as humidity is not already higher than is comfortable. It is well-known that greened surfaces contribute to improving the microclimate and air quality as well as buffering heavy rain water.

solar
decathlon
europe

Examples for the integration of vegetation, wetlands and evaporative cooling devices into the building's design are shown by Figures 1.43 to 1.46. Such approaches were proven to work well, for example, in SDE10 and SDE12 in Madrid with its warm but dry climate: in the 2012 AND house, stone slabs which were constantly flooded with water were installed into the external areas between the parts of the building. The 2010 GRE Team relied heavily on the use of outdoor plants to regulate the microclimate. The integration of vegetation into the design of a building can be further promoted in future Competitions as well as in European building practice, especially if the focus is on urban situations.

Almost all Teams in the SDE paid special attention to the air tightness of their building envelope. This optimization of the building envelope doesn't only help to maintain a comfortable indoor temperature especially during winter in colder climates, but also increases the efficiency of active cooling. For the efficient use of supply and return air ventilation and especially with regard to heat recovery, an air tight building envelope is mandatory.

solar
decathlon
europe

## 1.3 constructions & construction materials

Construction materials for small homes were traditionally selected on the basis of the local availability of resources and climatic conditions: whereas timber constructions are typically applied in the north of Europe, massive constructions dominate the housing stock in central and southern Europe. Buildings in the south particularly profit from the thermal inertia of massive constructions to buffer the summer temperature swing between day and night and allow for thermal comfort without active cooling. In most cases, thermal inertia is not significant for the space heating demand of a building. That makes light-weight buildings more suitable in heating dominated climates.

Prefabrication is a typical property of timber constructions and can be elementary building or modular building. The higher the degree of prefabrication is, the shorter the building assembly time is on site. The prefabrication and short assembly times are the major arguments why most buildings for the Solar Decathlon Europe are timber frame houses. Typical assembly times are between ten and fourteen days with some night-time assembly. In general, timber constructions are easier to assemble and problems with the mismatch of building elements at the junctions can be more easily solved by non-professionals. It is important to keep in mind that the houses at SDE are mostly built by students, most of whom have no practical training in the building profession.

**Table 1.5: Overview of the degree of prefabrication of the SDE houses and the main load bearing materials. The lowest degree of prefabrication is prefabricated parts like columns or beams which are not listed here because all Teams used them. The next higher degree is prefabricated elements like walls and the highest degree of prefabrication means that whole rooms or building segments are prefabricated. Listed here are only those Teams which chose to prefabricate at least elements of their building. Source: University of Wuppertal, Susanne Hendel**

| Year | Team | Prefabrication type | | Main Construction Material | |
|---|---|---|---|---|---|
| | | Elements | Modules | Wood | Steel/ Metal |
| 2010 | VGT | | X | X | |
| | ROS | X | X | X | |
| | HFT | | X | X | X |
| | BUW | X | | X | |
| | CEU | X | | X | |
| | GRE | X | | X | X |
| | HUT | X | | X | |
| | IAA | X | | X | |
| | TUC | X | | X | |
| | UDS | X | X | X | X |
| | UDV | X | | X | |
| | UON | X | | X | |
| | UPC | X | X | X | X |
| | AMP | | X | X | |

solar decathlon europe

| Year | Team | Prefabrication type | | Main Construction Material | |
|---|---|---|---|---|---|
| | | Elements | Modules | Wood | Steel/ Metal |
| 2012 | TRA | X | X | X | X |
| | AND | | X | X | |
| | ROM | X | | X | |
| | HTW | X | | X | |
| | RWT | | X | X | X |
| | BME | | X | X | |
| | CEU | | X | X | X |
| | UPC | X | X | X | X |
| | BUC | | X | X | |
| | DTU | X | X | X | |
| | TJU | X | X | X | |
| | EHU | | X | X | |
| | ABC | X | | X | X |
| | BRA | X | | X | X |
| | FAU | X | X | X | X |
| | STS | X | | | |
| 2014 | ROM | X | | X | |
| | DEL | | X | X | X |
| | ROF | X | | X | |
| | LUC | X | | X | |
| | FNX | | X | X | |
| | DTU | X | | X | |
| | REC | | X | X | |
| | CUJ | X | | X | |
| | OTP | X | | X | |
| | MEX | | X | | X |
| | PLT | X | | X | |
| | KMU | X | | X | |
| | SHU | X | | X | X |
| 2019 | DEF | X | | X | |
| | GUB | | X | X | |
| | KMU | X | | X | |
| | MIH | X | | X | |
| | PLF | | X | X | |
| | SEV | | X | | X |
| | TUB | X | | X | |
| | VAL | X | | X | |

solar decathlon europe

The majority of the Teams chose a design with prefabricated elements such as walls and roofs (55%), fewer went for modular designs (35%). This is mainly due to a lack of knowledge on modular building, the limited transportation sizes and the design limitations for ensuring the load statics of each module. For the same reasons, modular designs are not that common in Europe but are currently a topic of investigation. The main reason for this is the search for measures to lower relatively high construction costs [detail 2016].

The 2002 Energy Performance of Buildings Directive and its two modifications have increased the thermal property requirements of the building envelopes of new buildings in Europe. This results in more thermal insulation and more airtight buildings. Indoor prefabrication in a workshop is an essential approach to ensure such qualities at a reasonable cost level. Students at the SDE are trained to design and build prefabricated homes. They are ready to apply their knowledge in their future professional activity in an expanding market. Today, the market share of prefabricated timber homes is more than 40% in Scandinavia and more than 20% in Germany [schober 2018, p. 9]. There is room for an increase in this market share in Central Europe in comparison with the US market which has been fully dominated by prefabricated houses for decades.

The type of construction and materials used are important for the sustainability rating and the circularity potential of a building. A sustainability contest was introduced for the first time when the Competition was transformed from the US to Europe. This reflects the market introduction of sustainability ratings [dngb 2019] which cover more than the energy use in a building and include, in particular, the life cycle carbon footprint and circularity.

Figure 1.47 shows the SDE10 Sunflower house (TUC) on day nine of assembly at the event site. In 2010, the Teams had a total of seventeen days to assemble their houses [SDE10 site operation plan]. In order to shorten the construction time at the event site, the 2010 TUC Teams chose to prefabricate elements of their house; in Figure 1.48 the wall elements are already installed. The Team finished construction in time.

The SDE10 overall winner, the VGT Team designed and pre-constructed modules of their house in maximum transport sizes. Figure 1.48 shows the delivery of the main module on the night of day seven of assembly. This main module was supplemented by building elements such as the exterior shading, deck elements and the solar systems that were mounted on the roof. This Team had one of the fastest assembly times on site. This building was also optimized for mobility and was assembled within a few days on Times Square in New York and later in Chicago.

While in the SDE10 only six out of sixteen Teams used modular designs, in 2012 the number of Teams increased to eleven out of eighteen. One of the 2012 Teams was the Spanish Team from Seville with their house Patio (2012 AND). Figure 1.49 shows the delivery of one of the room modules during the assembly phase of the Competition. The prefabrication of entire room modules is the logical consequence of the building design as the rooms are separate from each other and only connected by a non-conditioned patio. The advantages of this design and the patio is also described in the chapter on the buffer zones.

solar
decathlon
europe

Figure 1.47: Construction of the 2010 TUC house on day nine of assembly at the SDE10 event site. Source: SDE, Flickr, Javier Alonso Huerta [sde flickr doc]

igure 1.48: Arrival of one of the modules of the 2010 VGT house at the event site on day seven of assembly. Source: SDE, Flickr, Javier Alonso Huerta [sde flickr doc]

Figure 1.49: Arrival of one of the modules of the 2012 AND house at the event site. Source: SDE, Flickr [sde flickr doc]

In order to examine the construction of the SDE houses, a distinction is made between the load-bearing main construction, the surface cladding inside and outside, the insulation and materials with room climate regulating properties.

The construction of the houses is very important for the acoustic properties, namely the sound insulation. The insulation level depends on the window and door ratio, the air tightness and the sound insulation properties of the opaque and transparent elements including their joints. Sound insulation is an ambitious task with respect to the light constructions. The sound insulations were tested with separate measurements in the two Spanish editions of the SDE [madrid 2014]. Acoustics experts have been responsible for choosing the façade of the houses on which the tests are carried out. Measurements were made on the most unfavourable facade. The measurement was done by the organisers according to the global method proposed in the ISO 140-5:1998. The sound insulation Dls,2m values in decibel (dB) for each of the 1/3 octave bands are calculated between 100 Hz and 5 kHz. Calculations have been done according to ISO 717-1:1996. All available points are earned above 42 dB. No points are earned if the acoustic value is equal or below 30 dB. Three Teams in the Competitions received a high sound insulation above 42 dB, most Teams manage to keep within the limits, but still some constructions fail with their acoustic performance.

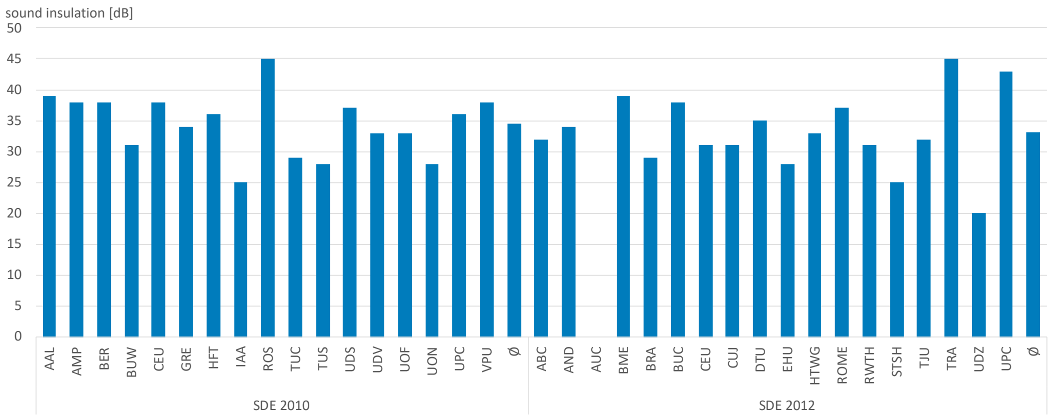



Figure 1.50: Comparison of the sound insulation of the facades of SDE homes tested in SDE10 and SDE12. Source: Technical University Madrid

solar
decathlon
europe

### 1.3.1 Load-Bearing Material

Wooden load-bearing structures were the preferred choice (90%) of the SDE Teams (Figure 1.51). Only a third of the SDE Teams (23) used steel as one of the main load-bearing materials. Six of these houses used steel as the only load-bearing construction. Timber and steel constructions both allow for a high degree of prefabrication. With a steel construction prefabrication of at least parts of the building is mandatory. Compared to timber, steel comes with the disadvantage that it is usually heavier. In addition, any misfits of parts cannot be resolved on site and new parts need to be ordered.

Supporting structures made of concrete were demonstrated in SDE14 by the Parisian Team PAR and in SDE19 by the Delft Team (2019 DEF). The 2019 DEF Team thereby demonstrated the transformation of a former office building for residential purposes and reused parts of the building's existing structure. Based on their country-specific background, in SDE10 the Team from Shanghai, China (2010 TUS) used bamboo for the building's load bearing structure (Figure 1.52). The house is an excellent example of a house built for a European Competition but with an Asian cultural background.

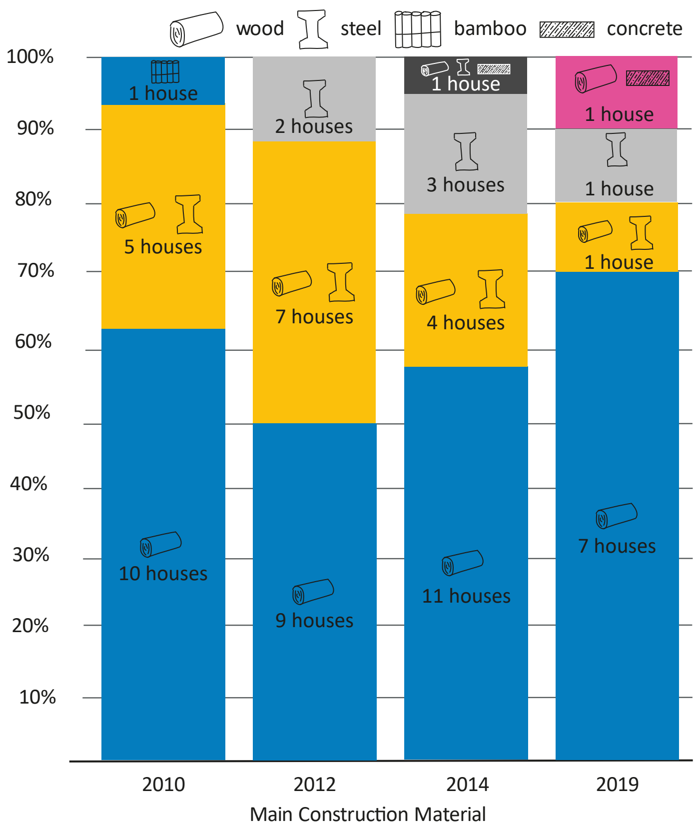



Figure 1.51: Representation of the utilized load-bearing materials with the distinction whether the structure was manufactured from one material or more.
Source: University of Wuppertal, Susanne Hendel

solar
decathlon
europe


Figure 1.52


Figure 1.52

Figure 1.52: The SDE10 TUS house demonstrates the use of bamboo for load bearing as well as cladding. Source: SDE, Flickr [sde flickr doc]

Figure 1.53: Massive constructions are not common in the SDE context. Because Teams only have 10 to 14 days to assemble their houses on the event site and all houses need to be transportable, constructions based on reinforced concrete are not feasible. However, the SDE19 focused on existing building renovations and the organization gave all Teams the unique possibility to request a building structure that would be built prior to the arrival of the Teams. Only the Teams DEF (MOR of the TU Delft) took advantage and requested a concrete structure. This structure is kept visible from the inside. Source: University of Wuppertal, Susanne Hendel

A rare material used in the SDE is concrete. Because the houses need to be transportable, simply and speedily assembled and disassembled, stone or concrete based constructions are not feasible. However, two out of 65 SDE Teams used concrete. For example, the MOR house of the 2019 Delft Team has a massive concrete load-bearing construction (Figure 1.53). This was only possible because the necessary concrete structure was built by the SDE19 organizers prior to the assembly period. The DEF Team prefabricated wooden parts and elements and build them on site into the existing concrete structure. Concrete constructions give the house a comfort advantage in summer due to their additional thermal inertia.

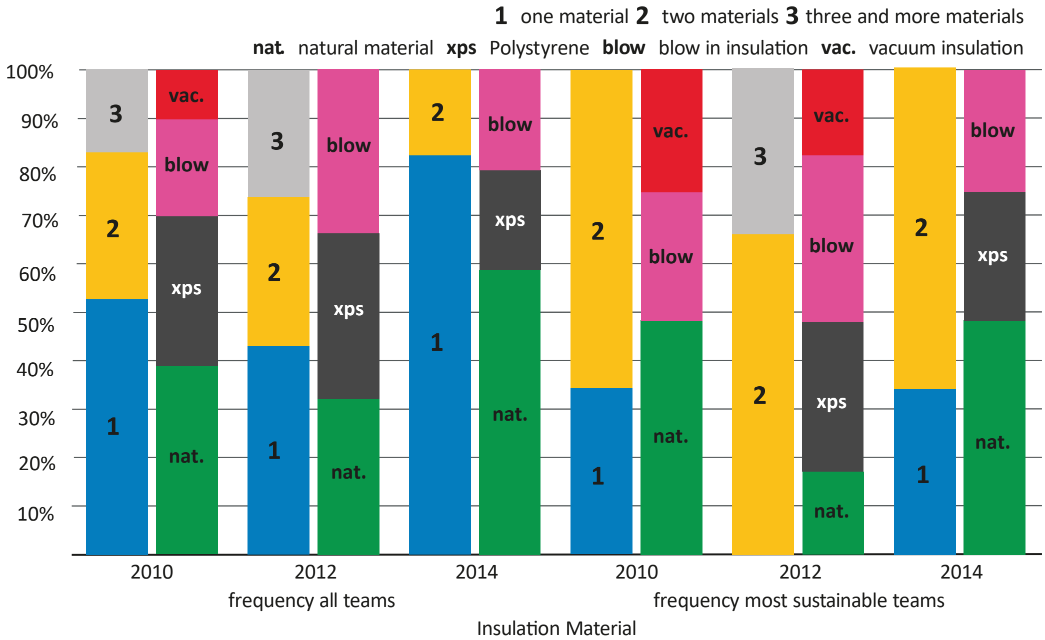
The timed constructions used in the SDE demonstrate highly insulated walls, floors and roofs. Due to the limited size of the building sites, Teams search for wall constructions with minimized thickness without loss of living area inside the homes. Most timber frame walls realize a given U-value with less overall thickness compared to massive constructions, making them more attractive with lower U-values set by the national building codes. In real life, buildings often use the full legal plot size and homeowners are not interested in thick walls which reduce the living area. Of course, sound insulation and other properties have to be studied and considered. Sound insulation was measured at most of the SDE editions in Europe, stimulating light constructions with sufficient sound insulation.

solar
decathlon
europe

### 1.3.2 Materials for thermal Insulation

As already discussed in chapter 1.2.1, thermal insulation of the building envelope is key issue. The materials utilized for insulation were more numerous than those for the load-bearing structures. Figure 1.54 provides information on the types of insulation applied. Insulation materials are classified by source in the categories for natural, mineral and synthetic materials [hillebrandt 2018, p. 86]. Natural and mineral fibres, materials such as hemp or mineral wool were favoured in the SDE. The main mineral insulation materials used were rock wool, mineral wool and foam glass. As synthetic insulation mainly expanded or extruded, polystyrene was installed. High performance vacuum insulation boards were demonstrated in various applications in SDE homes. Due to their high costs, these materials are preferably applied in situations where space is critical. Their application profits from the prefabrication of building elements or modules to prevent damage to the sensible material.

Figure 1.54: Representation of the insulation materials utilized. Source: University of Wuppertal, Susanne Hendel




In almost all cases, the insulation material was installed within cavities with the option of being removable. This is typical for prefabricated homes but is not the case for the general housing market in Europe. Composite systems for external insulation are a typical feature of massive buildings because of their economic advantage. The circularity potential of these constructions is lower compared to the systems applied in the SDE.

solar
decathlon
europe

Figure 1.55: Vacuum insulating panels visible at the 2010 UDS (Solarkit) house during assembly.
Source: SDE, Flickr, Javier Alonso Huerta [sde flickr doc]

Figure 1.56: Cork insulating boards visible at SDE10 during assembly.
Source: SDE, Flickr, Javier Alonso Huerta [sde flickr doc]

The Team from Seville, Spain (2010 UDS) prefabricated building modules which were delivered to the site with vacuum insulation boards already in place. Figure 1.56 shows the house on day nine of assembly at the SDE site.

Although natural fibre insulating materials and mineral insulating materials were most frequently used in SDE, only a few pictures of installation situations could be found. Since most of the houses were prefabricated in components, most of the insulation materials arrived at the event site already in place and cladded. An exception is the out of contest project shown in the Figure 1.56, which was built at the site in 2010. In this case, building modules, which were equipped with external corkboards, were brought to the site.

A detailed examination of the results of the sustainability contest show no direct correlation between the insulation material chosen and the sustainability contest scoring. However, the life cycle footprint of materials from natural sources is significantly lower in general. This makes them particularly favourable for large insulation thicknesses: the embodied energy of a material is constant for every cm of insulation but the operational energy saving per cm decreases by thickness.

### 1.3.3 Surface cladding

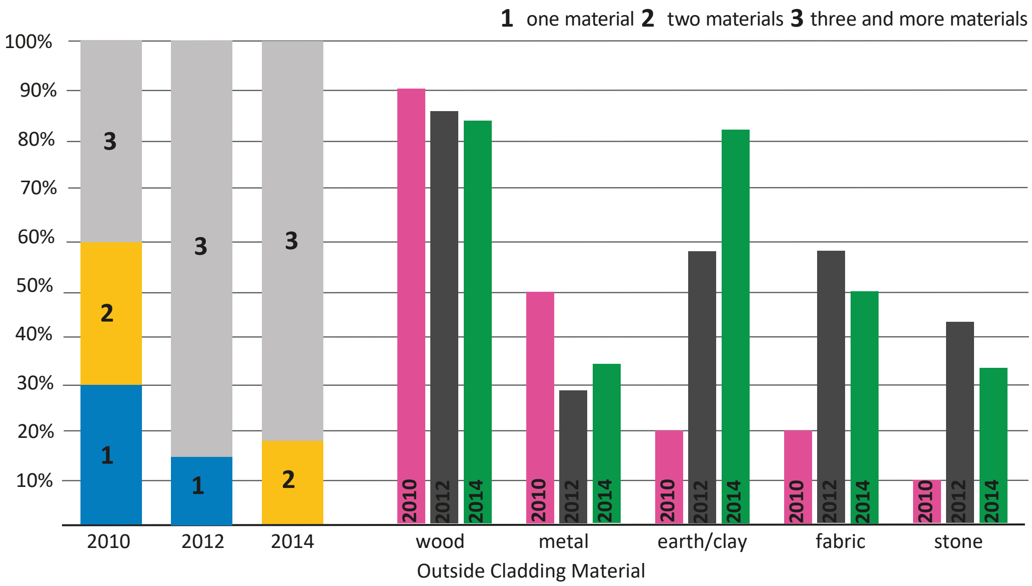
#### 1.3.3.1 Exterior surface cladding

Surface cladding is an essential design element. It can serve the building's efficiency with additional functions. The exterior surface cladding material is always in a design dialogue with the installed solar systems as solar systems usually occupy a large part of the building envelope of SDE houses. Apart from interior design aspects, the interior cladding influences the indoor climate. Interior surfaces can serve as hygro-thermal buffers depending on their physical properties. For the evaluation, the materials for the external shell and the surface cladding in the interior are considered separately.

solar
decathlon
europe

Figure 1.57: Recycled CDs as external cladding at the 2012 RWT house. Source: University of Wuppertal, Karsten Voss

Figure 1.58: Materials utilized in the SDE houses for the surface cladding of the external shell of the building. Source: University of Wuppertal, Susanne Hendel




About 80% of the SDE Teams used wood for the façade cladding and/or the exterior elements such as terraces and pergolas. The use of wood as a cladding material on a wooden load-bearing structure was preferred.

solar decathlon europe

By reviewing only, the three best Teams in the discipline for construction, all twelve winning Teams in the three SDE Competitions have selected not only a purely wooden load-bearing construction but also wood panelling for the walls. This can be explained by the positive image of wood as a construction material. Wooden cladding gives the construction visibility and is often associated with eco design. Single material constructions are easier to recycle than other constructions. The wood panelling was supplemented on 70% of the houses by other materials. These supplementing materials were metal, stone and textiles.

Half of the SDE Teams consider special climate-regulating materials or constructions such as clay or wall vegetation. Although no special experiments were undertaken to examine performance, the constructions contribute to the indoor climate conditions without active humidification or dehumidification.

Due to the sustainability contest, some Teams paid special attention to the cladding materials selected as regards their sustainability. In some cases, this led to unusual concepts. For example, the SDE12 RWT cladded the external walls with old CDs, which they melted together to form larger panels (Figure 1.58). Solutions like this demonstrate a creative approach to dealing with sustainability goals in the architectural language of a project. Of course, such approaches are easier to address in temporary buildings than in the general building stock. On the other hand, prominent examples such as the Europe Building of the European Council in Brussels exist and address recycling materials for new buildings [wiki]. Examples for the large variety of cladding materials in the SDE houses are illustrated by Figures 1.59 – 1.62.

Figure 1.59: Wooden outside cladding at the SDE10 HUT house. Source: SDE, Flickr, Flakes [sde flickr doc]

Figure 1.60: Translucent façade cladding at the SDE14 BAR houses. Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]

Figure 1.61: Metal outside cladding on the ventilated façade of the SDE10 ROS house. Source: SDE, Flickr [sde flickr doc]

Figure 1.62: Textile membrane as the outside shell of the SDE14 INS houses. Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]


Figure 1.59


Figure 1.60

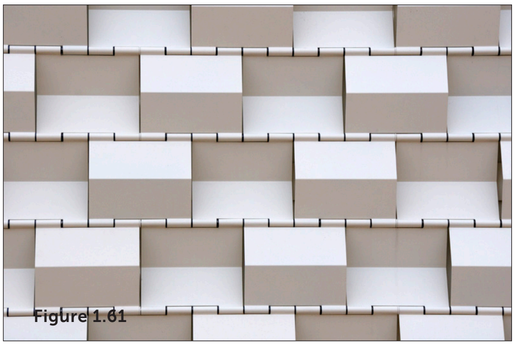


Figure 1.61


Figure 1.61

solar decathlon europe

1.3.3.2 Interior Surface Cladding

With regard to interior cladding, a classification can be applied for materials with or without special properties to improve indoor thermal comfort. Materials with special properties are, for example, latent heat-storing materials (phase change materials, PCM) for temperature regulation or materials such as clay for humidity buffering. Figure 1.63 gives an overview of the materials applied.

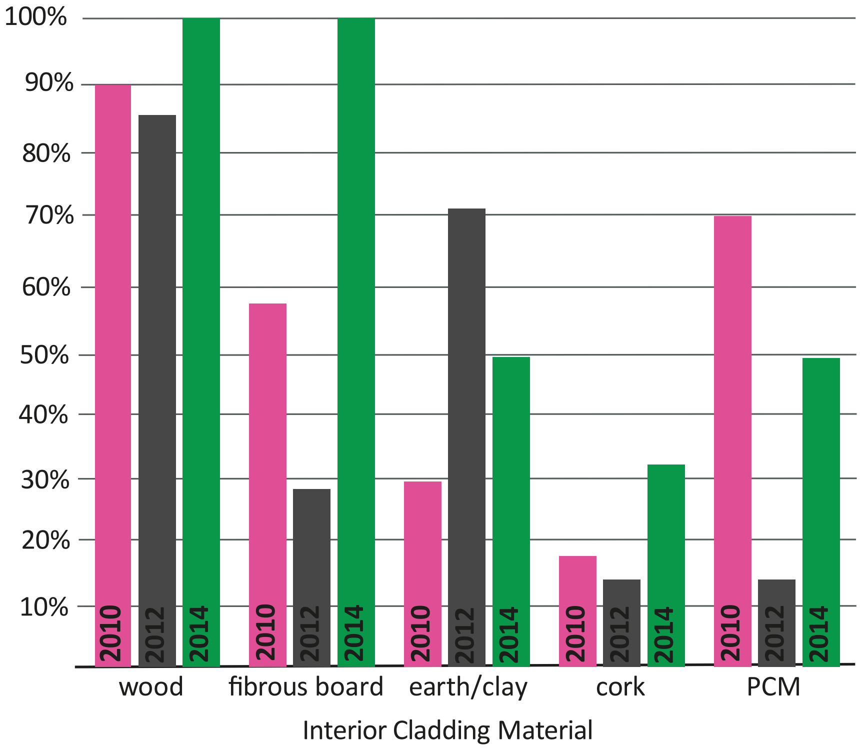



Figure 1.63: Distribution of materials used as interior cladding in the SDE houses. Source: University of Wuppertal, Susanne Hendel

Apart from wood which was once again the favourite material for interior cladding and PCM to increase the thermal mass of the constructions, some Teams chose clay cladding (Figure 1.66). Earth and clay cladding have the advantage of working as a combined hydro-thermal buffer. Over 90% of the SDE houses had wooden interior panelling or flooring (Figure 1.65). As with the exterior cladding, wood was supplemented in the interior spaces with at least one more material. Using bamboo as interior cladding was the direct consequence of using bamboo for all load-bearing constructions and exterior surfaces in the SDE10 TUS house (Figure 1.66).

The Figures 1.64 to 1.67 show examples of SDE interior designs. The visual identity of each house has been shaped by the used materials. The surface of materials defines the interior design by bringing material patterns and construction patterns into a room. Materials can also influence the shape of a room with their specific properties such as the textile membrane roof.
Some designs are definitely more experimental than those applied in the real market.

solar
decathlon
europe

Figure 1.64: Wooden interior design in the SDE10 HUT house.
Source: SDE, Flickr [sde flickr doc]

Figure 1.65: Bamboo interior in the SDE10 TUS house.
Source: SDE, Flickr [sde flickr doc]

Figure 1.66: Interior clay walls in the SDE10 AMP house.
Source: SDE, Flickr [sde flickr doc]

Figure 1.67: Interior design with membrane and wooden surface claddings in the SDE14 INS house.
Source: SDE, Flickr, Valeria Anzolin, Jason Flakes [sde flickr doc]


Figure 1.64


Figure 1.64


Figure 1.64


Figure 1.64

### 1.3.3.3 Thermal Inertia

The disadvantage of all prefabricated, light-weight buildings in summer conditions such as the SDE final Competition period is the lack of thermal inertia. Some Teams add thermal mass in the form of massive floor elements. An example is given with Figure 1.70. In this case the placements of the floor plates reflect the positions were the sun may hit the ground. With this approach, the additional elements reach the highest effect.

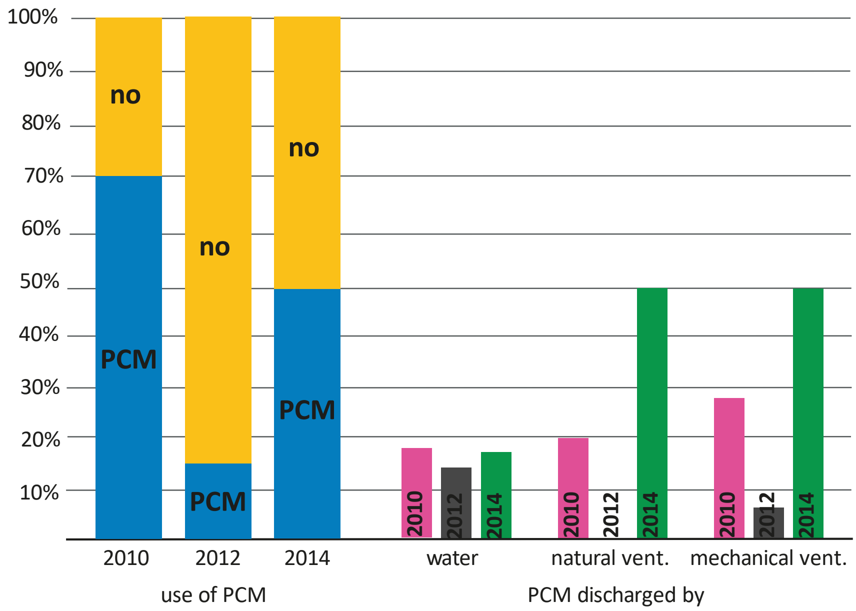
An innovative solution studied in many SDE homes is the application of phase change material (PCM) as part of the interior cladding (Figure 1.69). Materials are chosen with a phase change temperature 1 or 2° K below the maximum temperature for the summer thermal conditions in the Competition (typically 26°C). This allows the material to melt and store energy during the day with the aim of discharging it at night. Designed for summer thermal comfort, the materials are not significantly beneficial during winter as the melting temperature is too high.

PCM is a common generic term for materials such as paraffin or salt hydrates; paraffin can be micro-encapsulated and added to the plaster or gypsum boards. Ultimately, the materials do not differ visually from materials without paraffin, but the thermal storage mass can be increased to a certain extent. The upper limit of PCM content in such applications is mainly set by fire protection regulations as paraffin is flammable. Salt hydrates become part of separate constructions. Mainly bags or boards prove to be suitable. In the house MOR of the Delft Team in SDE19, salt hydrate plates were installed in cavities in the wall constructions, as shown here by Figure 1.71.

Usually, such PCM boards would not be visible, but the 2019 DEF Team left a window in the wall construction for demonstration purposes. In the 2019 DEF house, the PCM is connected to the HVAC systems and excess heat is discharged at night by mechanical ventilation. In most SDE houses, natural or mechanical ventilation is used to discharge the PCM.

Based on the monitoring data from the SDE Competitions, it is not possible to carry out a performance analysis which focuses solely on PCM.

Figure 1.68: Overview of the PCM applications in the SDE houses. The graphic shows the number of applications as well as the type of discharging designed. Source: University of Wuppertal, Susanne Hendel




An overview article on PCM use in SDUS 2005, 2007 and 2009 was published in

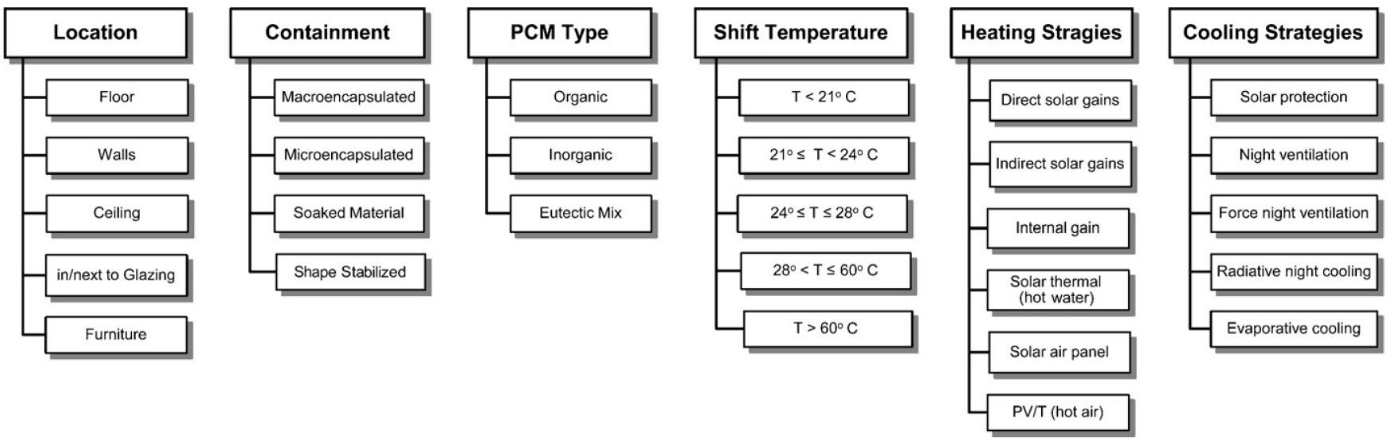



Figure 1.69: Overview of the factors influencing the performance of PCM applications in buildings. Source: [rodriguez-ubinas 2012]

solar decathlon europe

In about half of the houses, the thermal storage capacity of the construction was increased by the use of phase change materials. From the Teams using PCM, barely half select a passive discharging process. The PCM is discharged by means of natural night ventilation thereby avoiding the additional electricity usage caused by fans. On the other hand, active ventilation better secures the discharging process at suitable conditions such as sufficiently low outdoor temperatures at night.

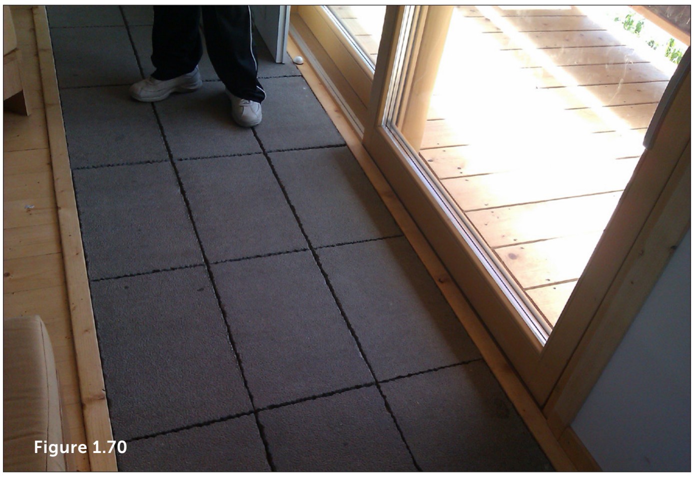




Figure 1.70: The PRISPA Team at SDE12 place thermal mass with concrete floor plates exactly in locations were the sun hits the floor. Source: University of Wuppertal, Karsten Voss

Figure 1.71: Example for a PCM panel behind interior cladding with a woodchip board in the Team Delft home for SDE19. Source: University of Wuppertal, Karsten Voss

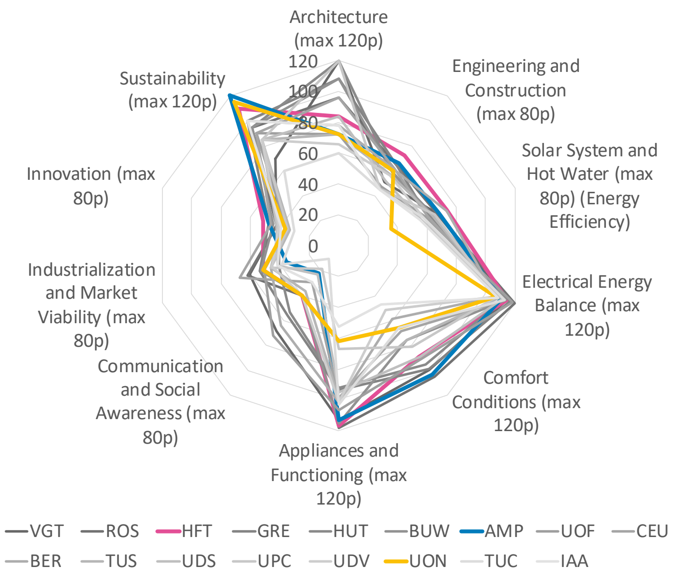
### 1.3.4 Sustainability in Construction

Sustainability was a jury contest in all SDE Competitions (Figure 1.72 to 1.74). All juries decided that houses with load-bearing structures made of one material only were advantageous compared to others. Their constructions were awarded places one to five out of about twenty in both the disciplines for construction and sustainability. Constructions that used the same material for load bearing as well as cladding were considered honest designs. These constructions have a higher recycling potential.

In addition to the choice of material, the type of structural connection plays an important role in the reusability of materials, building elements or entire buildings. In particular, the possibility of assembling and disassembling most SDE houses several times gives them a unique circularity. In addition to the choice of material, the fastening and connection elements are also relevant for quick and repeated assembly, disassembly and later recycling of the materials.

The spirit of using fewer materials and creating constructions that can be reassembled or recycled is an important message taken from the SDE to building practice. Building professionals could study many SDE house designs and constructions with regard to improved circularity.

solar
decathlon
europe



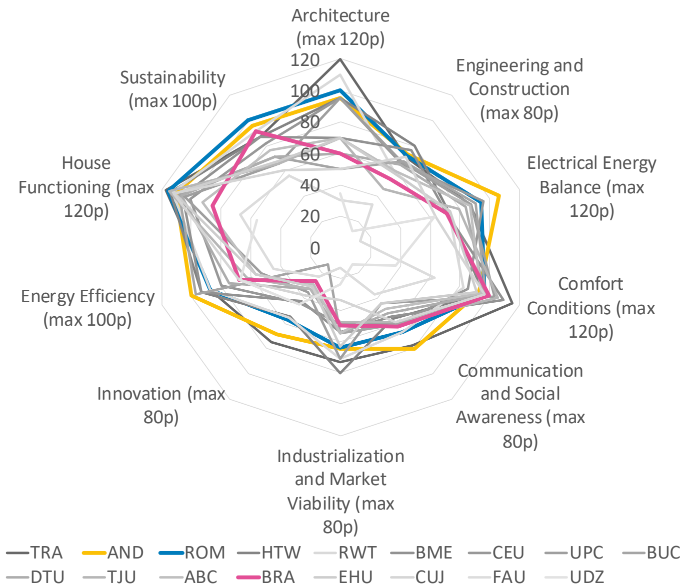




**Figure 1.72: Overview of the scoring dissemination of all contest and all Teams in the SDE10. Teams that scored best in the Sustainability contest are coloured. Source: University of Wuppertal, Susanne Hendel**

**1. AMP (pure material construction, prefabricated modules)**
**2. UON (pure material construction, prefabricated elements)**
**3. HFT (mixed material construction, prefabricated modules)**

**Figure 1.73: Overview of the scoring dissemination of all contest and all Teams in the SDE12. Teams that scored best in the Sustainability contest are coloured. Source: University of Wuppertal, Susanne Hendel**

**1. ROM (pure material construction, prefabricated elements)**
**2. AND (pure material construction, prefabricated modules)**
**3. BRA (mixed material construction, prefabricated elements)**

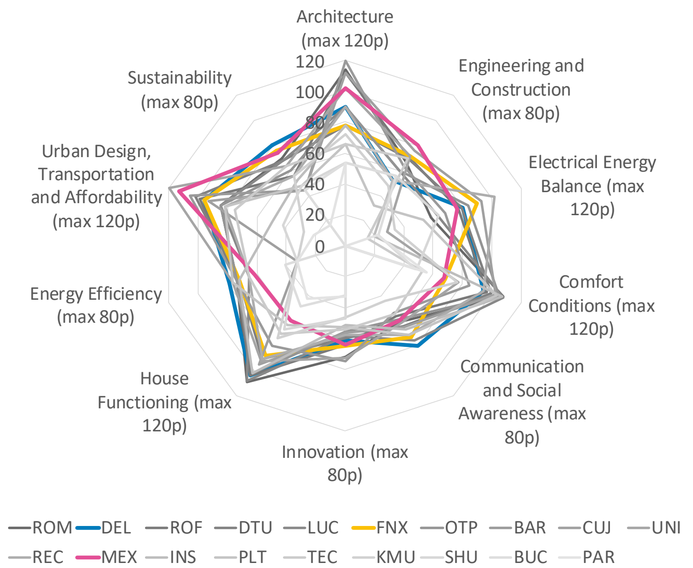



**Figure 1.74: Overview of the scoring dissemination of all contest and all Teams in the SDE14. Teams that scored best in the Sustainability contest are coloured. Source: University of Wuppertal, Susanne Hendel**

**1. DEL (renovation, mixed material use, prefabricated modules)**
**2. FNX (pure material construction, prefabricated modules)**
**3. MEX (pure steel construction, prefabricated modules)**

solar
decathlon
europe

# 1.4 solar system integration

As the Competition is about net zero or net energy positive solar buildings, there is a unique density of solar system solutions and related innovation. Due to their size, especially in relation to the size of the building, the solar systems (Figure 1.75) of the SDE houses are, in many cases, prominent design features. This is especially the case with regard to PV and less for solar thermal systems. Following a systematic analysis [munari-probst 2019] different approaches are considered with respect to

- **visibility:** how prominent are the solar systems in the architecture?
- **materiality:** is the material of the solar system different or identical to additional external cladding?
- **geometry:** is the solar system grating identical or different from the other external cladding?
- **detailing:** how are visible joints and connections solved to contribute to a convincing image?

The Figures 1.76 to 1.79 illustrate these aspects with selected examples. The technological aspects of the active use of solar energy in the SDE are considered in the separate report on 'Energy Engineering'.

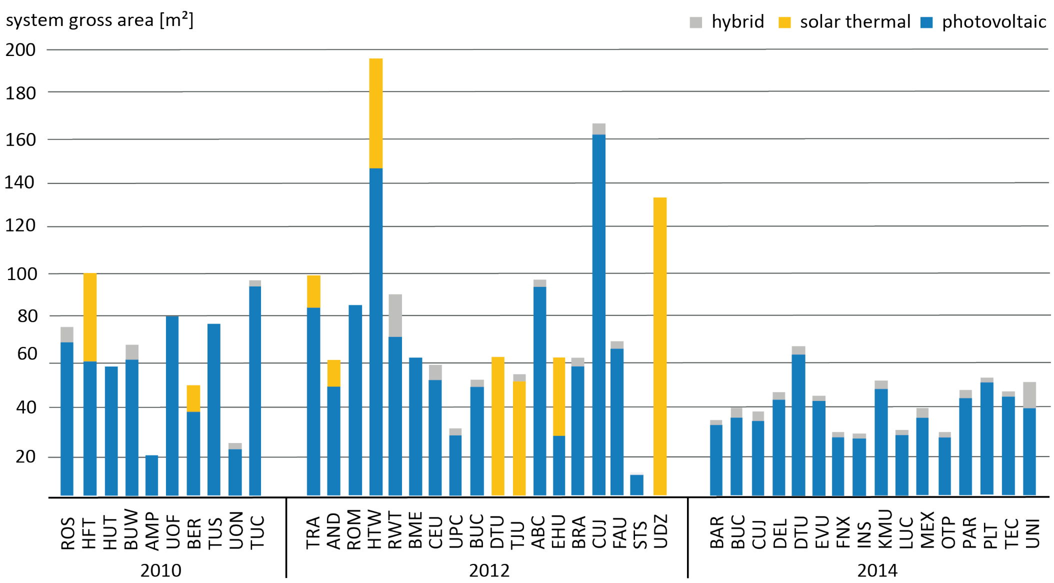



Figure 1.75: Size and solar system type used in the past SDE Competitions. Source: University Wuppertal [voss 2016]

solar
decathlon
europe

Figure 1.76: On the Counter Entropy 2012 (RWT) no solar systems can be seen.
Source: SDE, Flickr [sde flickr doc]

Figure 1.77: The SDE home+house of the Hochschule für Technik in Stuttgart (HFT) has coloured photovoltaic modules on the façade as its definitive design element.
Source: University of Wuppertal, Karsten Voss

Apart from energy from the solar village grid, solar energy is the only source of energy available to all SDE houses. However, using energy from the grid leads to a deduction of points. All SDE houses are characterized by extensive use of solar energy. However, the houses vary significantly with regard to the visibility of the solar modules. Whereas houses such as the SDE12 RWT house (Figure 1.77) have no solar systems visible to visitors, in houses such as the SDE10 HFT house (Figure 1.78) solar modules are the definitive design element on the building envelope.

The perception of the SDE houses differs not only because of the visibility of the modules but also because of their interaction with the other materials used in the building envelope. When choosing their materials, some of the Teams decided to visually integrate the solar modules as can be seen in the example of the SDE19 DEF house where solar modules were selected which have a similar appearance to façade cladding due to their matt surface. This type of façade cladding is standard on high-rise buildings. The SDE19 DEF house has no optical break between the façade cladding and the solar systems (Figure 1.78).

The SDE12 Ecolar (HTW) house deliberately foregrounded the contrast between the black solar modules and the wooden façade (Figure 1.79). In this case, the break in materials and colours used to lead a coherent design with the solar modules supplementing the formal language of the building.

Figure 1.78: The MOR house (DEF) at SDE19 presents a module for high-rise renovation. The façade cladding comprises matt photovoltaic modules which match the colour of the windows by a ceramic ink on the surface.
Source: TU Delft, Project Drawings

Figure 1.79: On the SDE 2012 Ecolar (HTW) house, the solar modules are in direct contrast to the wooden façade.
Source: University of Wuppertal, Karsten Voss

solar
decathlon
europe

The geometry of solar modules and their arrangement determines whether the systems are perceived as an added or integral part of the building. In the examples of both the SDE10 SML house (CEU) and SDE12 Unizar (UDZ) house, solar modules were installed on the façade to contrast with the other colours and materials used. The geometry of the CEU house modules complements the façade and they appear integrated (Figure 1.80). In contrast, the UDZ house modules appear to be added on due to their hexagonal form; they contrast with the rest of the building and the rest of the façade which is smooth and white (Figure 1.81).


Figure 1.80


Figure 1.81

Figure 1.80: One example of the integrated geometry of solar modules on the facade of the SDE10 SML house (CEU). Source: University of Wuppertal, Karsten Voss

Figure 1.81: On the SDE12 Unizar house (UDZ), solar modules were added to the façade. The hexagonal form of the modules emphasizes the complementary design approach. Source: University of Wuppertal, Karsten Voss

Apart from the positioning and design of solar modules, the load-bearing construction of the systems also determines the overall appearance which is also demonstrated by the range of solutions displayed at the SDE. Displaying the substructure can also be used as a design element which was the case in the SDE12 FAU house (Figure 1.82). This construction optically dominates the underlying building.

A different approach was taken by the SDE12 ROM Team. The solar modules were extended beyond the roof onto the façade as was the case on the FAU house; however, on the SDE12 ROM house a lean and non-dominant substructure was chosen (Figure 1.83).

solar
decathlon
europe



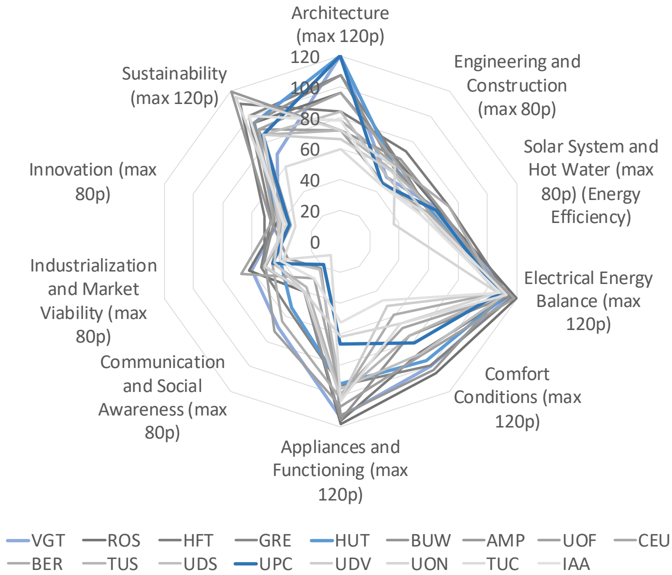
Figure 1.82: Solar system built over a dominant substructure on the SDE12 CEM NEM house (FAU). Source: University of Wuppertal: Karsten Voss

Figure 1.83: Solar system on a non-dominant substructure extending beyond the roof and over part of the façade of the SDE12 Med in Italy house (ROM). Source: University of Wuppertal Karsten Voss



The SDE houses are models for solar energy use; more surface area was given over to photovoltaic or solar thermal elements than is usually the case in building practice. It was important to integrate these elements in order to achieve a good score in the architecture discipline. Therefore, only a few Teams decided to add solar technologies onto their houses; however, this is currently the most common practice in the building industry. The integration of solar modules should always be seen within the context of the overall design.

Figure 1.84: Overview of the scoring of all contests and all Teams in the SDE10. Teams that scored best in the architecture contest are highlighted in blue. Source: University of Wuppertal, Susanne Hendel



solar
decathlon
europe

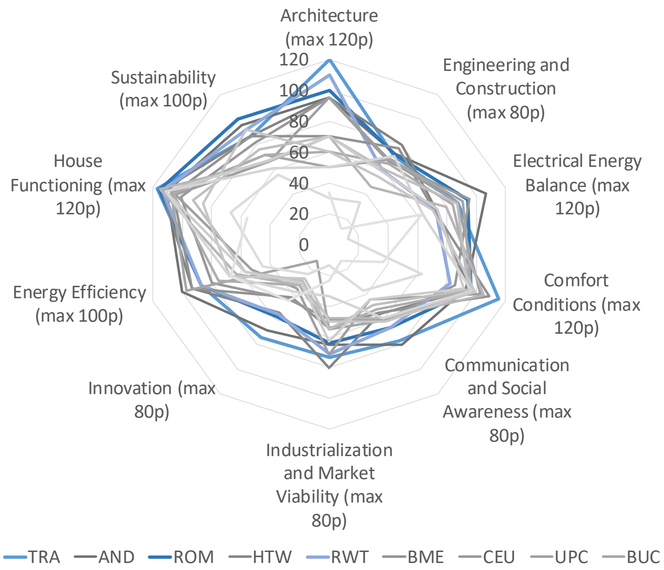



Figure 1.85: Overview of the scoring dissemination of all contests and all Teams in the SDE12. Teams that scored best in the architecture contest are highlighted in blue. Source: University of Wuppertal, Susanne Hendel

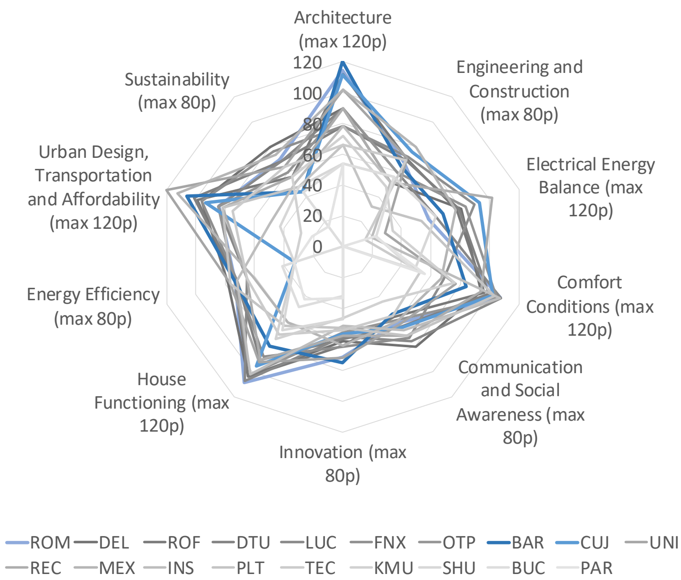



Figure 1.86: Overview of the scoring dissemination of all contests and all Teams in the SDE14. Teams that scored best in the architecture contest are highlighted in blue. Source: University of Wuppertal, Susanne Hendel

In each of the three Teams ranked highest in the architecture contest there are no overlaps with the Teams in the energy efficiency or sustainability contests.

All of the three top Teams integrated solar modules. However, the designs differ with regard to whether the solar modules are a visible or dominant part of the design or if these are barely or not at all visible to the visitor, as regards the colour and geometric design chosen and how the substructure design was executed.

All houses were awarded prizes in the architecture discipline and demonstrate different approaches to integrating solar energy technologies; therefore, they demonstrate options which can also be adopted by the building industry.

Some of the SDE houses differ fundamentally in their design from European building practice. This is primarily due to the lack of context and the building tasks which were often freely chosen. Most of the solutions presented at the SDE cannot be adopted as an overall concept by the building practice. However, the solutions presented for the integration of solar systems are transferable.

solar
decathlon
europe

# 1.5 conclusion

The SDE houses show a variety of approaches for future living and building and experience of them can bring impulses to European building practice. Although the SDE houses differ significantly from standard European buildings, they can serve as role models for future buildings.

Compared with standard European constructions, the SDE houses are significantly smaller, have a simple cubature, but an unfavourable form factor and a lack of thermal inertia; they also need to be transportable and lack an urban context. However, for each SD between ten and twenty of these special houses are built on the event site. All of them are comparable in size, usage and at each event even their location is the same. The large number of highly comparable, extensively documented and tested houses offered by the SD is unique. This enables knowledge to be gained about building solutions, their performance and also provides inspiration for their potential implementation in building practice. The differences between SDE houses and standard buildings plus the high expectations they need to fulfil in the Competitions can be interpreted as a framework that is more difficult than the framework standard buildings in Europe face; this makes the results even more interesting. The SDE houses present solutions for interior comfort and to construction challenges.

To secure a comfortable indoor climate without using an extensive amount of energy the SDE houses applied passive design strategies. The strategies evaluated here are shading systems, buffer zones, passive ventilation and the placement of vegetation and wetlands.

To deal with the challenge of building a transportable and highly efficient house with well-rated architecture, the SDE Teams paid special attention to their constructions and the materials used. The degree of prefabrication and choice of load-bearing and cladding material had a significant influence on the success of assembly and disassembly of the houses as well as on their performance during the Competition.

Based on the existing documentation, the houses can be best evaluated on the basis of their Competition scores. In particular, with regard to the contests ‘Energy Efficiency’, ‘Sustainability’ and ‘Architecture’, the houses were judged by an international expert jury. These contest scores were used to evaluate the passive building solutions implemented in the SDE houses. This evaluation showed that buildings with an extensive use of passive technologies are more likely to secure a comfortable and stable interior climate without the need of energy and active technologies.

Passive technologies contribute to the enhanced efficiency of the buildings. The effectiveness of individual passive measures cannot be determined within the scope of the SDE. However, in all SDE houses passive measures have been implemented to maintain interior comfort, especially since the introduction of the passive period. The example of the temperature measurements of the SDE12 houses could show that all of these houses were able to maintain a comfortable interior climate despite the challenging conditions they faced.

Passive technologies can be either dominant or integrated design elements. For example, solar chimneys or roof elements for a venturi-effect ventilation may be very visible on a building. Moreover, both elements are rather uncommon in European building practice and are hard to imagine in an inner-city environment. Nevertheless, both solutions could become more relevant in Europe, especially if periods of increasingly lengthy warm temperatures in the summer months are taken into consideration.

Other passive elements such as the ventilated façade, buffer zones integrated into the floor plan and shading elements are already an integral part of building practice. However, the SDE provides a large number of at times more experimental and unusual examples which could inspire building practice, which is in part rigid, to adopt new and more efficient ways of building.

For the dissemination of passive solutions to succeed, future Competitions should communicate their performance. Until now, only point scores and measurements have been published. The point scores of the jury disciplines do not per se provide evidence of what was considered as particularly constructive and of what could be of particular interest to the building profession and an interested public. The performance results are difficult for an interested public to interpret and are even difficult for experts to fully comprehend without any additional documentation of the surrounding conditions.

The members of the jury agreed that honest constructions with just one material are more sustainable than structures which use different materials for the load-bearing structure, insulation and cladding. Constructions with material purity have an increased recycling potential; moreover, it opens up new possibilities for building practice if the houses can be transported and easily converted. The SDE houses are all designed for rapid assembly, disassembly and reassembly. A high level of prefabrication has proven to be advantageous. The prefabrication of buildings is already becoming more common in Europe and has a growing market share. In this respect, the SDE provides new innovative examples and new impulses.

SDE houses provide examples for the integration of elements for solar energy use into the design of the building. In contrast to photovoltaic or solar thermal elements which are usually added subsequently to a building, the SDE houses demonstrate a use of solar energy which has been conceived of as part of the design. The SDE shows that the use of solar energy can be either a dominant part of the building envelope or may not be visible on the building at all. A transfer of SDE concepts to building practice can be of benefit to building practice, in particular with regard to the growing need for surfaces for solar energy use.

The SDE buildings are compact demonstrations of the possibilities for maximizing a building's energy efficiency, sustainability in combination with an ambitious design. Ideas and innovations especially with regard to construction and consequent design could and should affect building practice.

solar
decathlon
europe

## References

* **[sde flickr doc]** Solar Decathlon Europe 'SDE Picture Documentation.', https://www.flickr.com/photos/sdeurope/albums/with/72157631550799795
* **[voss 2016]** Voss, K., Russel, P., Hendel, S.:'Solar Decathlon Europe and the Energy Endeavour Initiative,' proceedings of the Eurosun, pp. 1–9, 2016
* **[sde14 2014]** S. D. E. 2014 Organizers, SD EU 2014/ Rules / v5.0, no. June. 2014
* **[ec housing 2011]** European Commission, 'Housing space per person,' 2011
* **[voss 2011]** Voss, K. Musall, E. (ed.): Net Zero Energy Buildings - International Projects on Carbon Neutrality in Buildings, DETAIL, ISBN-978-3-920034-80-5, Munich, 2011, http://shop.detail.de/eu_e/net-zero-energy-buildings.html
* **[sde10 2010]** Solar Decathlon Europe Organizers, SOLAR DECATHLON EUROPE 2010 RULES AND REGULATIONS SUMMARY OF REVISIONS ( DRAFT 5 . 0 ). Spain, 2010
* **[sde12 2012]** S. D. E. Organizers, Solar Decathlon Europe 2012 Rules. Spain, 2012
* **[detail 2011]** Solararchitektur 4 – Die deutschen Beiträge zum Solar Decathlon Europe 2010, Detail Verlag, München, 2010, ISBN 978-3-920034-48-5
* **[living lab 2019]** 'Living Lab Low3.', http://livinglab-low3.blogspot.com. [Accessed: 16-Sep-2019]
* **[cubity 2014]** TU Darmstadt, 'Cubity,' 2014, https://cubity.de. [Accessed: 09-Feb-2019]
* **[darmstadt 2019]** 'Founder Lab Würzburg.', https://www.techno.architektur.tu-darmstadt.de/techno/forsch_diss_techno/founder_lab_wuerzburg/bauforschung_mehr_1.de.jsp. [Accessed: 09-Feb-2019]
* **[detail 2016]** Barankay, T.: 'Modulare Bauformen – Trend oder Zukunftsmodell ?,' DETAIL, 2016
* **[schober 2018]** Schober, K.-S., Gruda, K., Jandt, J., Malik, P.: 'Prefabricated housing market in Central and Northern Europe – Overview of market trends and development,' Munich, 2018
* **[dngb 2019]** DNGB, 'DNGB System.', https://www.dgnb-system.de/de/. [Accessed: 09-Feb-2019]
* **[hillebrandt 2018]** Hillebrandt, A., Riegler-Floors, P., Rosen, A.: Atlas Recycling: Gebäude als Materialressource. Wuppertal: Detail, 2018
* **[wiki]** 'Europagebäude,' Wikipedia, https://de.wikipedia.org/wiki/Europagebäude
* **[rodriguez-ubinas 2012]** Rodriguez-Ubinas, E., Ruiz-Valero, L., Vega, S., Neila, J.: 'Applications of Phase Change Material in highly energy-efficient houses,' Energy Build., vol. 50, pp. 49–62, Jul. 2012
* **[munari-probst 2019]** Munari-Probst, M., Roecker, Chr.: Criteria and policies to master the visual impact of solar systems in urban environments: The LESO-QSV method, Solar Energy, vol. 184, pp. 672-687, 2019
* **[terrados 2014]** Terrados, F.J., Moreno, D.: 'Patio' and 'Botijo'- Energetiv Stragies architectural integratin in Patio 2.12 prototype, Energy and Buildings, vol. 83, pp. 70-88, 2014
* **[madrid 2014]** Medición in situ del aislamiento acústico al ruido aéreo de fachadas - Solar Decathlon 2010 and 2012, Laboratoroa de Acoustica y Vibrationes de a Escuela Tecnica Superior de Arcquitectura, Polytechnic University Madrid, 2010, 2012

*EC TENDER #: ENER / C2 / 2016-502*

# solar decathlon europe

# 2. energy engineering

*KARSTEN VOSS, SUSANNE HENDEL, MORITZ STARK, ANDREA BALCERZAK*
*UNIVERSITY OF WUPPERTAL*

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS"
WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID,
BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# table of contents


| | | PG |
|---|---|---|
| **2.1** | **The Competition framework** | **65** |
| 2.1.1 | Regulations | 65 |
| 2.1.2 | Energy-related Disciplines and Monitoring | 68 |
| **2.2** | **Solar energy harvesting** | **70** |
| 2.2.1 | Solar Power | 70 |
| 2.2.2 | Solar Thermal Systems | 78 |
| **2.3** | **Energy efficient devices & system concepts** | **83** |
| 2.3.1 | Appliances | 83 |
| 2.3.2 | Heating, Ventilation, Air Conditioning and Domestic Hot Water (HVAC/DHW) | 85 |
| 2.3.3 | Controls | 93 |
| **2.4** | **Energy balance & building grid interaction** | **96** |
| **2.5** | **Outlook** | **101** |

# 2.1 the competition framework

**2.1.1 Regulations**

All Competitions to date related to 'all-electric' homes. Apart from electricity, the only option alongside solar power is ambient air as a heat source or heat sink. Ground and groundwater heat or cold on the site cannot be included in the concept. The use of fossil fuels, biomass, biogas and hydrogen on the site is not permitted. This is primarily on the grounds of infrastructure feasibility and financing for temporary (event) structures and subsequent use of the site in question. Based a central event concept, all houses are built on the same site. It is also designed to allow a fair comparison of the various solutions. In public relations, however, care must be taken to ensure that all-electric homes are not presented in a one-sided way as the only sustainable option for the future, as urban energy solutions in particular may take other approaches. The idea of a heating and cooling network for the SDE19 buildings was ultimately not pursued following initial planning. An urban setting was also the context for that initial idea.

The scope for the energy concepts is thus centred on supplementing a largely solar energy supply with air-coupled heat pumps or refrigeration systems. In the light of the growing use of renewable energies in the electricity grids of many European countries, the focus on electricity as an energy source reflects a current trend.

As organisers seek to stage a public event with as great an attendance as possible, all Competitions to date have been held in the warm and sunny months of the year. This means that the demand for heating is usually low during the Competition period, and there has been - in line with the location - a greater (Dubai) or lower demand for cooling (Madrid, Versailles, Szentendre). Figure 2.1 shows the heating and cooling hours calculated for a model building from SDE10 in realistic conditions of use such as ventilation, internal heat sources and operation of the shading systems. The number of hours per year in which the room temperature is within the comfort range of 21°C to 25°C without heating and cooling operation was calculated (named 'neutral hours'). Hours above 25°C were cumulated and defined as cooling hours, and hours below 21°C were cumulated and defined as heating hours. As a result of the moderate climate during the planned Competition period in late summer, the heating and cooling systems will not be in operation at all at SDE21 in Germany. In all European Competitions, however, the houses must provide simulation calculations to proof the year-round suitability of the energy concepts as part of the requirements. An example of this is shown in Figure 2.2. This requirement also helps to ensure the usability of the houses after the actual Competition phase. For the most part, subsequent use has been in the country of the given Team and therefore in the climatic conditions of that country. Evidence has therefore generally been provided for both the climate of the Competition host country and of the home country of each Team.

solar
decathlon
europe

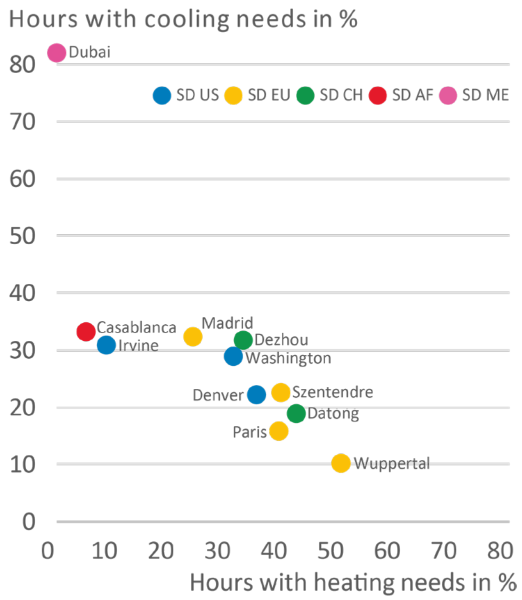



Figure 2.1a: Annual evaluation of free-floating temperatures at all event locations. The results are broken down by heating demand hours and cooling demand hours. Neutral hours are the difference between 100% and the sum of the heating and cooling hours. Neutral hours describe the state where the indoor temperature is in the comfort range without heating and cooling (21°C – 25°C). Source: S. Hendel, University of Wuppertal

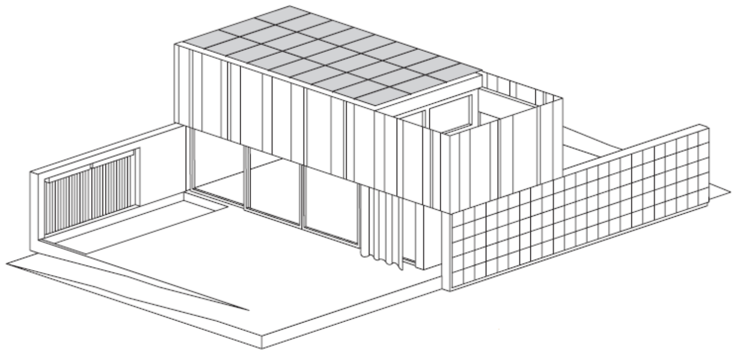


Figure 2.1b: Illustration of the Wuppertal house at SDE10 [Detail 2011]. This house was used as an example to simulate the indoor climate at all event locations. Source: S. Hendel, University of Wuppertal

Conditioned floor area: 49 m2; clear room height: 4.8 m; window-to-wall surface ratio: 25 %. Average thermal transmittance of opaque surfaces: 0.1 W/(m²K); average window thermal transmittance: 0.8 W/(m²K); air tightness ($n_{50}$): 0.6 1/h; exterior sunscreen with shading factor: 0.2; sunscreen active above 200 W/m² incident radiation; ventilation with heat recovery with 85% efficiency and overheat protection through increased window ventilation, activates when the indoor temperature is higher than 22°C.

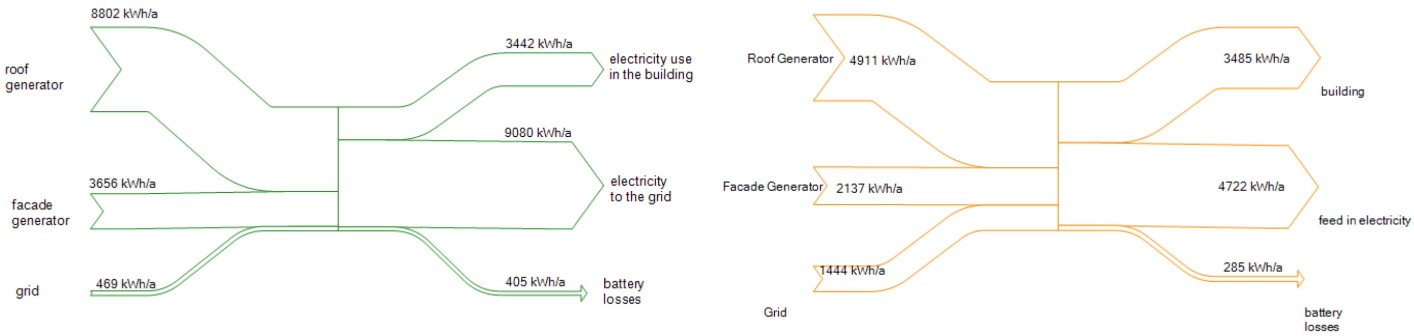



Figure 2.2: Energy flow diagrams (Sankey diagrams) for the annual energy performance of the house illustrated with Fig. 2.1b for Madrid (2010 Competition conditions, left-hand diagram) and Wuppertal (standard conditions, right-hand diagram). Source: University of Wuppertal

solar
decathlon
europe

The first SDE10 in Madrid has one important focus on stimulating Teams to maximize PV power installations on the building roofs and facades. This creates a large variety of building integrated solar systems. To increase the practical relevance of the small buildings including the overall building costs, more recent Competitions have lowered the limits for photovoltaic system peak power or the maximum storage capacity of batteries. This is designed to maintain and even stimulate the high challenges regarding building energy efficiency for all Teams. In view of the large enveloping surface per living space compared to conventional buildings (refer to Report on Building Design & Construction), large solar power systems are otherwise able to compensate even for high consumption by less efficient buildings. This is particularly true for Competitions in sunny locations or at the height of summer. The maximum photovoltaic system power was limited to 15 kWp at the very first SDE in 2010. This limit was subsequently reduced to 10 kWp (2012) and then 5 kWp (2014/19). The current Rules for SDE21 set out a further reduction to 3 kWP. The reason for this is the standard practice set for multi-family dwellings: the larger number of storeys means even less enveloping surface is available per living space in practice, in particular roof surface. In some cases, upper limits were also set for the costs of the solar technology used and evidence of market availability was required. Both these requirements reflect the tension between innovation and practical relevance. As the SDE houses are connected to the public grid, all standard certificates of conformity must have been obtained, in particular for the inverters, so that a negative impact on the grid can be ruled out.

A number of Competitions have been held to date in which the use of batteries was permitted. At the first three Competitions in the USA, batteries were a technical necessity because there was no grid connection. The requirements specified independent operation for the duration of the Competition only. There were no requirements for year-round independent operation, which would indeed not be technically feasible even with batteries. With the introduction of grid-connected operation, the focus has changed from self-sufficient buildings to nearly zero, net zero or energy plus buildings [sartori 2011] [voss 2011]; calculations showing the annual energy balances must now also be provided. Batteries are used for the optimised adjustment of generation and consumption at SDE12/14/19 and at SDE21 also for flexible building-grid interaction.
In a step similar to that for photovoltaic power, maximum storage capacities were first introduced in the European Competitions. The limit for 2014 and 2019 was a nominal capacity of 6 kWh; this has been reduced to 2.5 kWh for SDE21. This type of specification has a major influence on the building design, the technology used and the overall building energy concepts.

Tables A2.1 and A2.2 in the Annex to this report provide an overview of the requirements.

To ensure the functionality of the buildings, and electrical loads as well as air conditioning during the Competition, practical specifications for the operation of household appliances and consumer electronics apply in all Competitions. Specific activities at given times such as laundry, running hot water and cooking, the entertainment of guests in the evening and, in some cases in the US and in Dubai, the operation of electrically powered vehicles, have also been included in the requirements. SDE21 will include mobility on the level of urban cargo bikes in the energy discipline.

solar
decathlon
europe

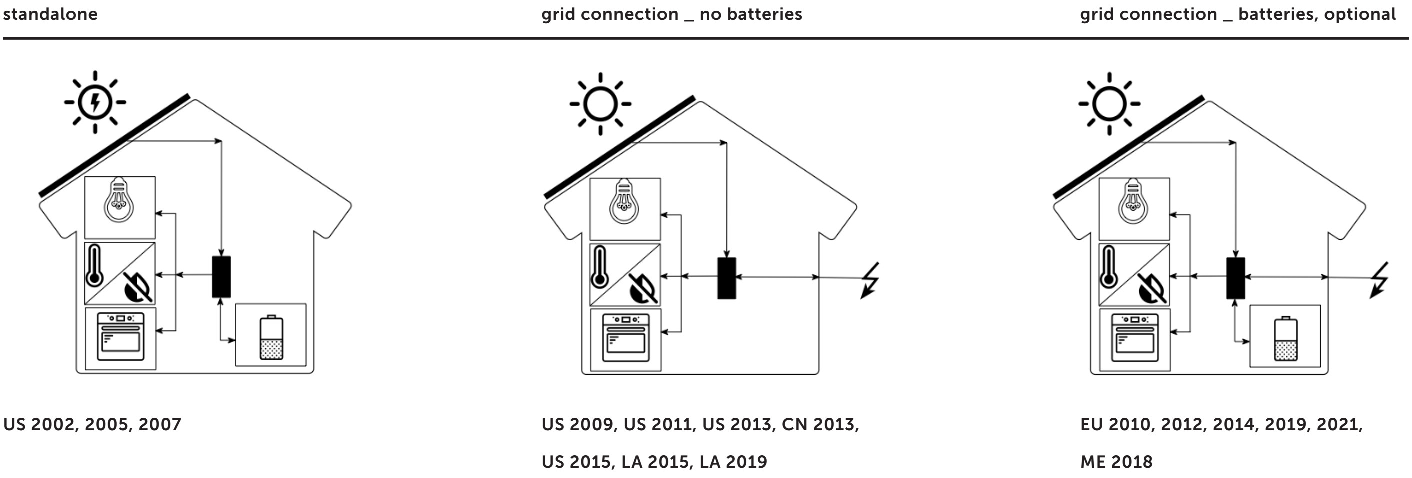



Figure 2.3: Electric grid availability and battery utilisation in SD Competitions, Source: S. Hendel, University of Wuppertal

### 2.1.2 Energy-related Disciplines and Monitoring

Each SD Competition evaluates the houses in ten different disciplines. The names, Rules and points for those disciplines shape the profile of each Competition. Points are awarded mainly by juries, but also on the basis of measurements. The evaluation of the energy balance is always one of the core areas and, like the function of the houses and the indoor climate, is based on measurements. A summary of the relevant disciplines and available measurements can be found in Tables A2.3 and A2.4 in the appendix section to this report.

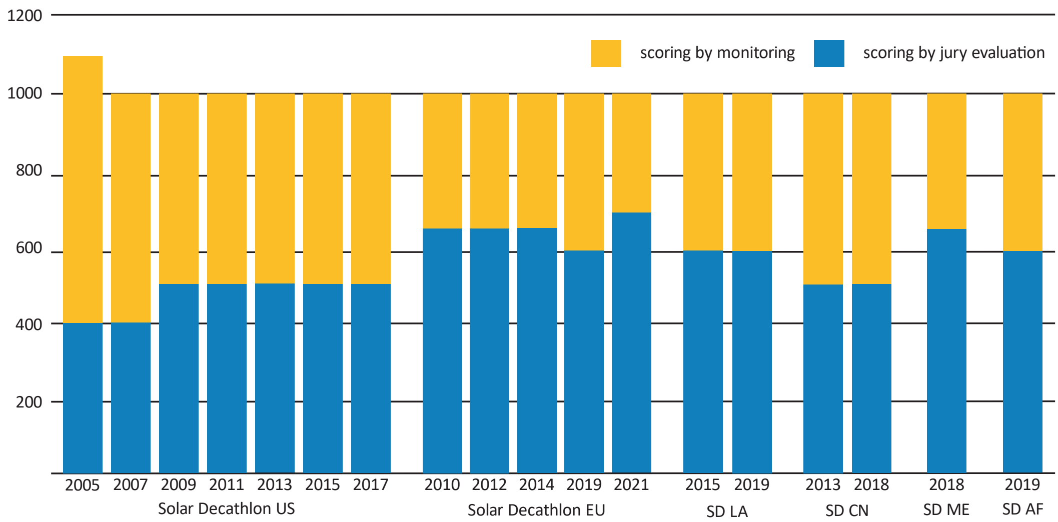



Figure 2.4: Breakdown of points (maximum scores) at SD Competitions. Between 36% and 64% of the total points are awarded by juries. Overall, the proportion of the score awarded by the jury in SDE is higher than in SD, SD LA, SD CN and SD AF. SD ME scoring is based on SDE the 2014 experiences. Please note that the Competition in the US 2005 used a higher total number of points with 200 instead of typically 100 for architecture.

Source: S. Hendel, University of Wuppertal

solar
decathlon
europe

Different intervals for monitoring have applied at the different SDE Competitions. For example, the data for SDE10 and SDE14 are available in one-minute intervals. Data at SDE12, on the other hand, were only recorded in fifteen-minute intervals. All these measurements have been compiled and processed for the knowledge platform in such a way as to allow further use in future (https://building-competition.org/). The organisers have not made available the data from SDE19 at the time of producing this report. Evaluation of measurements has always primarily served the ongoing evaluation of the houses in a Competition in comparison to each other (scoring). The results reflect the given climatic conditions and Competition Rules for the operation of the houses. Comparisons between Competitions are therefore only of limited use. Scientific or research use has not been the focus to date and would only be possible to a very limited extent. For SDE21, modifications to the regulations that should make this easier have already been planned.

solar
decathlon
europe

## 2.2 solar energy harvesting

### 2.2.1 Solar Power

2.2.1.1 Photovoltaics

Photovoltaic systems are a mandatory component of all energy concepts and occupy large areas of the SD houses. Table 2.1 lists the characteristics of the systems installed at SDE. Technical characteristics include cell type, system size and rated output. Most Teams opt primarily for modules with crystalline silicon-based solar cells as these offer a higher output. This reflects the current market situation globally. Monocrystalline cells are preferred because of their higher efficiency. That efficiency advantage is even greater when compared to thin-film cells [couty 2020-1]. A significant limitation on maximum system power has led to an increase in the variety of cell types used, as the aim is no longer simply to achieve maximum yield from a given area. Technical progress in thin-film cells, above all for the building integration market, is also contributing to greater interest in this field (BIPV: building-integrated photovoltaics). Despite the limitation on power, photovoltaic systems remain a key design element of most SDE houses; see report on 'Building Design and Construction'. The wide-ranging use of modules is evident in the varied designs [Cronemberger 2014].

Despite their small size, there are houses with photovoltaic systems covering almost 100 m² (SDE10: HFT, SDE12: EHU), which is about twice the conditioned floor space. The average system size was 7 kWp per 50 m² floor space equal to 140 W/m². The ratio of installed capacity to floor space decreased significantly in the Competitions from 2010 to 2014 as a result of changes in the Rules (Table 2.2, Figure 2.5): Larger floor spaces were permitted and the maximum power was lowered in 2014. Ratios are thus getting closer to those in systems in standard market buildings that meet the requirements of net zero or energy plus buildings. Accompanying research has found average values of just under 70 W/m² for single-family energy plus dwellings in Germany (Effizienzhaus Plus) [bmi 2018]. The process thus promotes the development of buildings that are genuinely relevant for building practice.

The size, orientation and angle of systems on the individual buildings, together with the quality of installation, determine the electricity yield during the Competition period. Quality of installation relates to structural aspects such as module ventilation and shading, and to electro technical aspects such as electrical adjustment between the modules and inverters. Figure 2.5 gives the example of the results for SDE14. As climatic conditions differ between the different Competition locations, a comparison across Competitions is not useful. Solar radiation on the systems has to date not been measured. Conclusions on the quality of system design and installation (performance ratio) therefore cannot be drawn. SDE21 is introducing such measurement for the first time.

solar decathlon europe

Table 2.1: Features of photovoltaic systems on SDE buildings. The completeness of the data reflects the available documents for the individual buildings. Source: University of Wuppertal

CFA: conditioned floor area, Mono: monocrystalline silicon cells, Multi: multi crystalline silicon cells, PVT: photovoltaic thermal hybrid solar collectors, CPVT: concentrating photovoltaic thermal solar collectors, CIGS: second generation of thin-film modules, BIPV: building-integrated photovoltaics. The abbreviations of the Team names are based on those used on the building Competition knowledge platform.

| Edition | Team | Cell type | System size $m^2$ | Nominal power kWp | Building conditioned floor area $m_{CFA}^2$ | Specific power $W_p/m^2_{CFA}$ | Additional function |
|---|---|---|---|---|---|---|---|
| **2010** | **ROS** | mono | 70 | 12.6 | 55 | 229.1 | Night sky radiation cooling |
| | **TUC** | mono | | 10.1 | 44 | 229.5 | PVT, shading |
| | **BER** | mono | | 8.4 | 52.8 | 159.5 | Night sky radiation cooling, shading |
| | **VGT** | | | 5.7 | 52.8 | 108.0 | |
| | **UDV** | | | 10 | 46.4 | 215.5 | |
| | **HFT** | | 99 | 9.0 | 52.1 | 172.7 | Coloured PV |
| | **UON** | multi | 24 | 2.8 | 72 | 38.2 | |
| | **AMP** | mono | 16 | 3.2 | 46 | 68.5 | |
| | **HUT** | mono | 59 | 9.0 | 42.4 | 212.3 | |
| | **IAA** | mono | 70 | 8.5 | 57.4 | 148.8 | |
| | **BUW** | mono + multi | | 10.1 | 48.6 | 207.8 | Fixed shading |
| | **UPC** | multi | | 4.2 | 42 | 100.0 | |
| | **UDS** | mono | | 9.6 | 51.7 | 185.7 | |
| | **TUS** | mono | | 10 | 42 | 238.1 | PVT, shading |
| | **GRE** | mono | | 13.8 | 44.7 | 308.7 | PVT, shading |
| | **UOF** | | 80 | 14.6 | 46 | 317.4 | CIGS |
| | ***average*** | | | 8.8 | 49.7 | 183.7 | |
| **2012** | **DTU** | | 70 | 9.2 | 59 | 155.9 | BIPVT |
| | **TJU** | | 56.6 | 8.8 | 61.6 | 142.2 | |
| | **UPC** | mono | 30.0 | 4.3 | 45.5 | 94.9 | |
| | **CUJ** | thin film | 160 | 11.4 | 54.4 | 208.6 | |
| | **CEU** | thin film, multi | 51.6 | 7.2 | 56.6 | 126.3 | |
| | **ABC** | multi | 32 | 6.2 | 69.4 | 89.3 | CPVT, night sky radiation cooling |
| | **FAU** | multi | 67.6 | 9.2 | 49.2 | 187.8 | |
| | **RWT** | thin film | 77.2 | 6.8 | 61.8 | 109.2 | Night sky radiation cooling |
| | **AND** | mono | 69.3 | 11.3 | 69.6 | 162.6 | PVT |
| | **BRA** | mono | 66.6 | 11.0 | 55.6 | 198.6 | CPVT |
| | **BME** | mono, thin film | 47.5 | 9.0 | 45 | 200.7 | CPVT, night sky radiation cooling |
| | **BUC** | mono | 55 | 8.0 | 77.6 | 103.1 | |
| | **ROM** | multi | 74.7 | 11.8 | 55.5 | 213.3 | CPVT |
| | **STS** | | | 3.5 | 58.23 | | CPVT |

solar decathlon europe

| Edition | Team | Cell type | System size $m^2$ | Nominal power kWp | Building conditioned floor area $m_{CFA}^2$ | Specific power $W_p/m^2_{CFA}$ | Additional function |
|---|---|---|---|---|---|---|---|
| **2012** | **HTW** | multi | 35.8 | 1.2 | 67.6 | 17.8 | CPVT, night sky radiation cooling |
| | **UDZ** | thin film | | 1.0 | 62.4 | 16.0 | |
| | **TRA** | mono | 13 | 2.0 | 68.8 | 29.1 | PVT |
| | **EHU** | mono | 91.2 | 12.0 | 49.1 | 244.1 | CPVT |
| | ***average*** | | | 7.4 | 58.3 | 131.1 | |
| **2014** | **ROM** | mono | 25 | 5.0 | 55.5 | 91.0 | |
| | **DEL** | mono | 44 | 4.9 | 85 | 57.6 | |
| | **ROF** | thin film | 15 | 4.7 | 55.4 | 84.8 | Shading |
| | **LUC** | mono | 14 | 4.7 | 73.3 | 64.1 | |
| | **FNX** | multi | 25 | 3.9 | 52.9 | 73.7 | |
| | **OTP** | mono | 15 | 4.9 | 110 | 44.5 | |
| | **DTU** | mono | | 2.6 | 66.5 | 39.1 | |
| | **REC** | mono | | 4.9 | 104 | 47.1 | |
| | **BAR** | mono | 29 | 4.5 | 137.6 | 32.7 | |
| | **CUJ** | | | 4.7 | 75.7 | 62.1 | |
| | **UNI** | multi | | 5.0 | 71.3 | 70.1 | |
| | **PAR** | thin film | 40 | 3.2 | 52 | 61.5 | Roof shading, large area luminescent solar concentrator technology |
| | **INS** | thin film | | | | | Membrane-integrated PV |
| | ***average*** | | | 4.5 | 72.8 | 60.6 | |
| **2019** | **BUD** | | | 5 | 70 | 71.4 | |
| | **DEF** | mono | | 5 | 51 | 98.0 | |
| | **GUB** | hybrid | 29.8 | 5 | 69.19 | 72.3 | PVT |
| | **KMU** | hetereo-junction | 25.11 | 4.875 | 62.53 | 78.0 | |
| | **MIH** | mono | | 5 | | | |
| | **PLF** | poly | 13.4 | 2.24 | 120 | 18.7 | |
| | **SEV** | | 36 | 4.8 | 80 | 60.0 | |
| | **TUB** | mono | 46.76 | 4.97 | 65 | 76.5 | |
| | **UPC** | poly | 22.92 | 3.3 | 108.2 | 30.5 | |
| | **VAL** | mono | 30.53 | 5 | 54.2 | 92.3 | |
| | ***average*** | | | 4.5 | 75.9 | 66.4 | |

solar
decathlon
europe

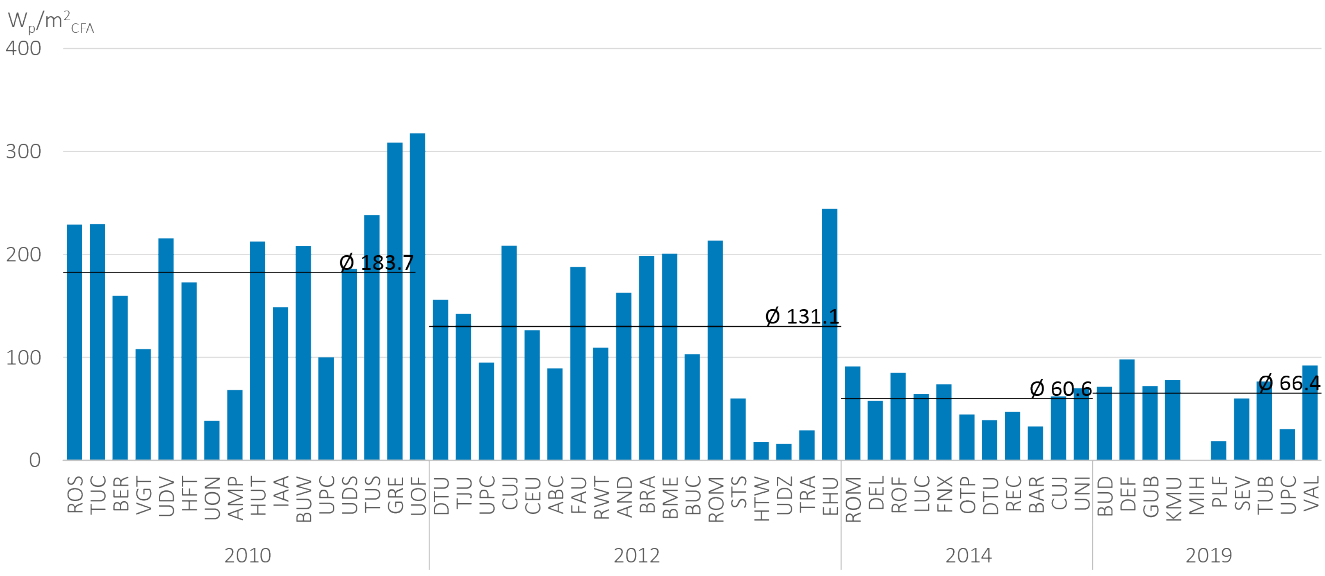



Figure 2.5: Correlation between the installed power of the PV systems and the conditioned net floor area of the houses in the European Competitions in 2010, 2012, 2014 and 2019. The relevant information is not available for all houses. Source: S. Hendel, University of Wuppertal

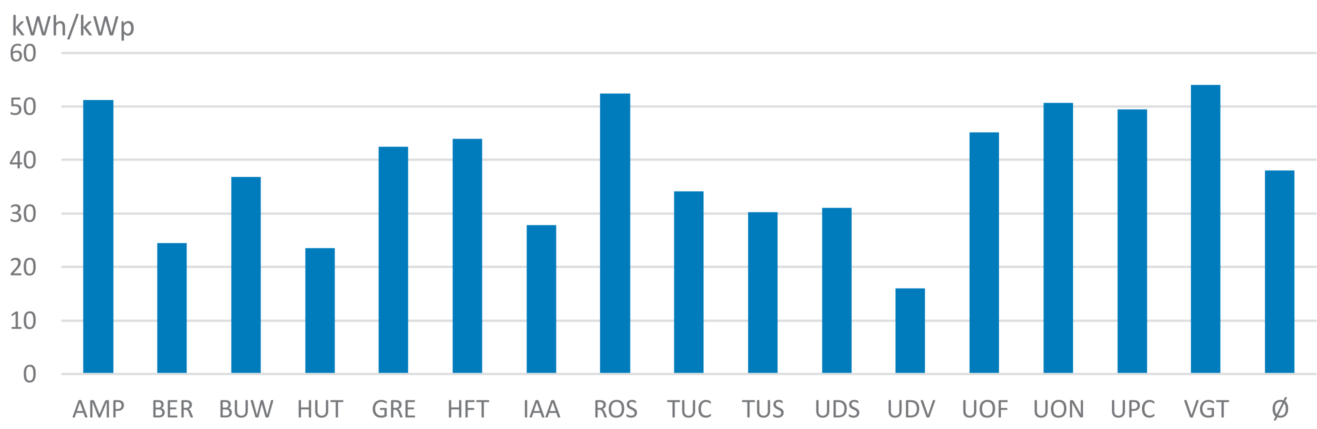



Figure 2.6: Specific yield of photovoltaic systems during the Competition period of 10 days in relation to the installed capacity at SDE10 in Madrid. The average yield was 38 kWh per kWp installed power. The differences are a result of the quality of system technology, electrical adjustment and the angle and orientation of the various systems. Source: University of Wuppertal

Table 2.2: Average PV system sizing in the European editions of the Solar Decathlon. Source: University of Wuppertal

| | | 2010 | 2012 | 2014 | 2019 |
|---|---|---|---|---|---|
| Installed power | kWp | 8.9 | 7.4 | 4.5 | 4.5 |
| Installed power per conditioned house floor area | kWp/m²cfa | 183.7 | 131.1 | 60.6 | 66.4 |

solar
decathlon
europe

The technical and architectural examples of photovoltaic systems on SDE buildings support the growing market for such systems on buildings in Europe. Such systems are a central element of the European Energy Roadmap. The vision in the Roadmap is for almost all electricity to come from renewable sources by 2050. According to a survey by the European statistical office eurostat, renewables generate about 30% of electricity in the 28 EU countries in 2016 [eurostat 2019]. In Germany, the figure was already 48% by 2019, with solar power generation accounting for 9% [energy charts 2020]. In the light of Competition for land for agriculture and significantly higher costs for ground-mounted systems, the expansion of photovoltaics on buildings is a central element of the European energy strategy.


Figure 2.7

Figure 2.8


Figure 2.9


Figure 2.10

Figure 2.7: home+ (HFT) at SDE10 is a good example of the visible use of crystalline PV modules over a large area. Modules were integrated into the roof and also into the facade of the building, where coloured cells were part of the design. The PV areas together are about twice as large as the floor space. Source: [sde flickr]

Figure 2.8: The Armadillo Box created by the French Team (GRE) at SDE10 also made wide-scale use of photovoltaic systems. The concept used PVT hybrid modules, which covered the roof and the upper section of the building. The solar 'hood' on the top of the building is not directly attached to the roof structure and is therefore extremely well ventilated. Source: SDE Flickr, by Javier Alonso Huerta [sde flickr]

Figure 2.9: At SDE14, installed PV system capacity had already been limited to 5 kWp. One example of the relatively small PV systems at the Competition is the DTU 2014 house. Individual modules were integrated into the glass roof of an outer buffer zone. Source: SDE Flickr, by Valeria Anzolin and Jason Flakes [sde flickr]

Figure 2.10: Another example of subtle PV system integration is the OTP 2014 house. Here, modules were only installed on the roof and were almost invisible to the visitors. Source: SDE Flickr, by Valeria Anzolin and Jason Flakes [sde flickr]

The examples implemented with the SDE houses help to increase acceptance of photovoltaic solar energy use in buildings amongst visitors to the Competitions and in reporting. They showcase a wide range of design and integration options for solar modules, and also use a number of multipurpose components. In addition to design aspects, competitors need to consider Competition for space and function in buildings, which otherwise reduces the space available for solar power use. Examples are the combination of solar cells with shading or as part of glazing to make use of daylight. Hybrid systems of photovoltaics and solar collectors for thermal solar energy use are also used. This allows the absorbed heat at the solar panels to be utilized and the solar cells also to be used for nocturnal radiation cooling to cool water (refer to section 2.2.2). The reduced module temperature may increase the efficiency of power generation, depending on the technology used. The following pictures show examples of the multi-purpose use of solar power systems and the application of new technologies.

solar
decathlon
europe

A good overview of systems available on the market is provided by the www.solarintegrationsolutions.org information platform, which was created as part of research by the International Energy Agency (IEA).

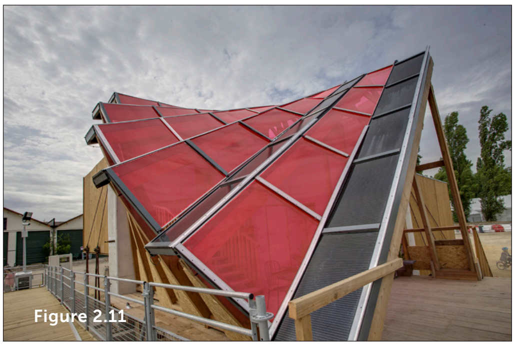


Figure 2.11

Figure 2.11: The solar cells in the PAR 2014 house use fluorescent plastic (PMMA) to focus light on solar cells at the edges using total reflection. Source: SDE Flickr, by Valeria Anzolin and Jason Flakes [sde flickr]


Figure 2.12

Figure 2.12: Thin-film modules in the INS 2014 house enable integration into the building envelope, which consists mainly of a membrane. Source: SDE Flickr, by Valeria Anzolin and Jason Flakes [sde flickr]


Figure 2.13

Figure 2.13: PVT hybrid modules form the roof of the Med in Italy house (ROME 2012). Source: SDE Flickr [sde flickr]

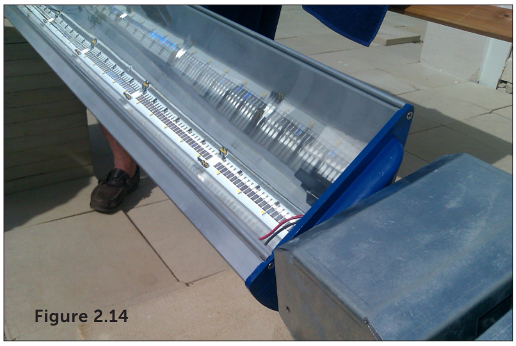


Figure 2.14

Figure 2.14: Single-axis tracking concentrating PV using Fresnel optics at the Sumbiosi house at SDE12. S ource: University of Wuppertal

### 2.2.1.2 Batteries

Grid-connected operation of the SDE houses ensures a power supply even at times when too little or no solar energy is available. This reflects standard practice in Europe. However, it means that the proportion of solar energy generated by the building that the building directly uses itself (self-consumption rate) and the degree of self-sufficiency (proportion of electricity consumption covered directly by the solar power system) remain comparatively low. A large amount of solar power is fed into the grid, and power is then also taken from the grid when required, most often in the early hours of the morning and at night. The situation can be improved by storing the electricity generated in batteries [couty 2020-2]. The objective is to balance out daytime and night-time power, not longer-term or indeed seasonal storage. However, altering self-consumption is the priority, as any form of energy storage involves losses. Storage losses of around 10 % for short storage times are currently typical.

In European building practice, batteries are still rarely used because of their high acquisition costs. The falling costs of electricity storage – primarily a result of growing demand in the mobility sector – together with rising electricity prices for end customers, lower payments for electricity fed into the grid and subsidy schemes that vary from country to country are leading to the slow development of the market.

solar
decathlon
europe

It is therefore an advantage that the houses in the more recent SDE Competitions use this technology in a wide variety of ways to investigate the functionality and the significance (refer to section 2.4). These include adapted, approved inverter concepts that support such system concepts. Table 2.3 provides an overview of the battery technologies and storage capacities used. In 2010, all batteries used were lead-acid based, but Teams in later Competitions increasingly used lithium-ion and lithium-ion/ iron phosphate batteries. The latter show advantages with respect to fire protection and the correlated danger. Typically no special measures were undertaken for fire protection at the location of the batteries inside the buildings and no extra ventilation is provided.

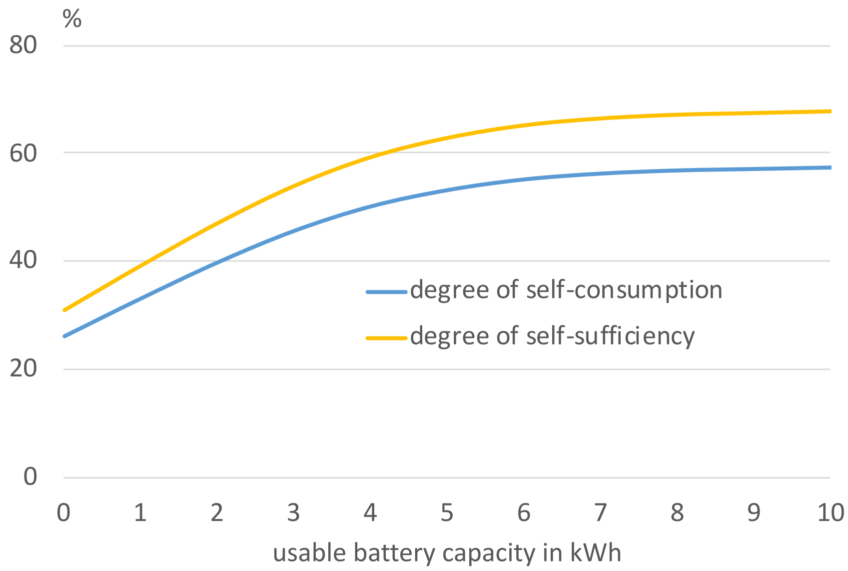



**Figure 2.15: Relationship between the degree of self-consumption /degree of self-sufficiency and battery capacity for a small residential building with annual household electricity consumption of 2,750 kWh, a heat pump, a solar thermal system and a 5 kWP solar power system. The data are based on simulations for a site in Germany. Source: University Wuppertal**

Batteries were allowed as part of the energy concepts in all European Competitions to date, but how they were scored differed. In 2010, for example, almost no batteries were used, although they were in some cases documented in the energy concepts of the buildings. A common design would be for around half of the houses' daily electricity consumption. An average total load of 314 W in the household electricity circuit at SDE14 (see section 2.3.2) would mean a necessary usable storage capacity of 3.75 kWh. As the calculations in Figure 2.15 show, this roughly doubles the self-consumption rate and self-sufficiency. The sizing in the SDE Competitions was generally slightly larger, which offered benefits in terms of points. In standard building practice, cost-effectiveness considerations usually result in smaller systems [García-Domingo 2014].

solar
decathlon
europe

The Rules of the SDE Competitions in 2014 and 2019 promoted the use of batteries as the avoidance of load peaks and network load (power peaks, house adjustment to network load state) and matching demand and consumption (temporary generation-consumption correlation) had a positive effect on the achievable score.

Table 2.3: Batteries used in SD houses. Only Teams for which documentation about the batteries was available are listed.

Source: University of Wuppertal

| Edition | Team | Battery Type | Capacity in kWh |
|---|---|---|---|
| 2010 | BER | Lead-acid | |
| | BUW | Lead-acid | 7.2 |
| | CEU | Lead-gel | 5.5 |
| 2012 | CUJ | Lithium-ion | 5 |
| | CEU | | 6 |
| | ABC | | |
| | AND | Lead-acid | |
| | HTW | | |
| | TRA | Lithium-ion | 5 |
| 2014 | BUC | Lead-acid | 5 |
| | KMU | Lead-acid | 6 |
| | LUC | Lithium-ion | 5 |
| | OTP | Lithium-ion | 5.5 |
| | REC | Lead-acid | 5.28 |
| | ROF | Lithium-ion | 4 |
| | ROM | Lead-acid | 4 |
| | UNI | Lithium-ion | 5.76 |
| 2019 | BUD | LiFePO4 | 6 |
| | DEF | Lithium-ion | 5 |
| | GUB | Li-NMC | 6.5 |
| | KMU | Lithium-ion | 6 |
| | MIH | | 6 |
| | PLF | LiFePO4 | 1.2 |
| | SEV | Lithium-ion | 6.6 |
| | TUB | LiFePO4 | 5.5 |
| | VAL | LiFePO4 | 6 |


Figure 2.16

Figure 2.17

Figure 2.18

Figure 2.16: Four externally mounted batteries (bottom) with lead-acid technology at an SD house at SDE12, Source: K. Voss, University of Wuppertal

Figure 2.17: Externally mounted battery box (left-hand box) with lithium-ion technology at an SD house in the US Competition in 2017. The capacity is listed at 13.5 kWh. Source: K. Voss, University of Wuppertal

Figure 2.18: Small battery pack with lithium-ion technology as part of indoor house installation at the SD house of the MOR Team in the SDE Competition in 2019. Source: K. Voss, University of Wuppertal

### 2.2.2 Solar Thermal Systems

An increase in solar thermal energy use would appear important in the light of the growing significance of domestic hot water in the heat balance of energy-efficient buildings: whilst efficiency measures to reduce demand for space heating and cooling are having an impact, the demand for heat for domestic hot water still remains constant. The required temperature level for domestic hot water is also higher than in the case of floor heating for space conditioning as typically implemented with heat pump based systems. Solar thermal system can increase the annual COP of heat pump based heating systems by taking over the main fraction of the higher temperature heat demand.

Small-scale solar water heating systems and solar combi systems for combined hot water preparation and space heating for detached single-family houses and apartment buildings, for multi-family houses, for hotels and for public buildings represent more than 90% of annual installations worldwide [iea shc 2019]. This traditional mass market has come under considerable pressure in Europe over the past few years. One reason is the drastic decrease in the price of PV systems while the prices of solar thermal systems remain more or less constant. Another aspect is the relatively complex system technology compared to the simplicity of grid-connected PV systems. Key elements are energy efficient thermal storage and suitable hydraulics and controls together with high system integration with less risk of installation failures [haeberle 2020].

Unlike PV, solar thermal systems almost always require storage in the given building. This is because excess heat cannot be stored in a public grid for later use. This would only be the case with heat networks, which have not to date been implemented at the SD villages. The storage together with the heat load is also the basis for the sizing of the collector area. Unlike with PV, this cannot flexibly be adapted to architectural requirements, for example a design that covers the entire roof. The usual system sizes for small single-family dwellings today are 4 $m^2$ for domestic hot water only and 10 $m^2$ for typical solar combi systems. In the DHW case 1 $m^2$ per person is a typical system size, corresponding to an indicator of 0.02 collector area per $m^2$ floor area. Many systems with standard collectors in SDE houses are larger (refer to table 2.4). This indicates the broader use of the systems and/or in some cases the support from the system manufacturers to overcome the economic disadvantage of large systems. Typical hybrid collectors are particularly larger and concentrating collectors are particularly smaller. Thermal storage was mainly realized by insulated hot water tanks. Some Teams experiment with phase change materials or thermo-chemical heat storage to receive a higher storage density and less thermal losses. The large variety of storage volumes reflect the diversity in system integration.

In contrast to photovoltaics, solar thermal systems are not a compulsory part of houses in the competition, but almost all homes apply solar collectors (2010: 88%, 2012: 94%, 2014: 100%, and 2019: 70%). This reflects the high acceptance and market penetration of such systems in building practice, especially for small, new-build residential homes. Unlike for PV, there has to date been no measurement of the yield in the competitions, which would in this case be the heat yield. As a consequence no information about the operation and performance of the systems can be evaluated from SDE monitoring data.

In reflection of the market situation in Europe [iea shc 2019] many Teams apply standard flat pate or vacuum tube collectors. On the other hand a variety of specialized collectors are considered such as uncovered absorbers, drain back systems, solar thermal concentrators, solar air collectors and many forms of hybrid collectors. Another aspect that reflects the market situation is that most of the systems are installed on the roofs of the buildings, on flat or inclined roofs. The few examples of façade integration are for solar combi systems that also contribute to heating or for hybrid collectors. As SDE is held during the summer months, such systems are essentially not a productive way of improving a Team's score in the monitored energy performance. Moreover, façade integration of solar thermal collectors still remains a difficult architectural task. The standard systems available on the market are typically not designed to be directly visible, but Teams try to experience convincing approaches (Figure 2.23, 2.24).

As in actual building practice, PV and solar thermal systems are competing for the areas on the building envelope exposed to sun. This is apparently also influencing the SDE Teams. Due to the reduction in permitted installed power for PV in SDE 2012 and 2014 more space was made available and more solar thermal systems were applied. Another way to resolve competing space requirements is to combine electrical and thermal solar power systems. This leads to so called PVT collectors (photovoltaic thermal). SDE demonstrates a large number of examples. Around 1 million $m^2$ of such systems have already been installed in Europe [iea shc 2019]. Most of these systems are based on PV modules with air or water cooling at the back without additional glazing at the front to reduce heat losses. Without additional front glazing the focus is the generation of solar power. Many SDE competitors choose this PVT system option, some use the thermal circuit behind the panels for radiative cooling in the night. This option is possible in the case of flat mounted systems and a climate with mostly clear summer skies. Still the cooling contribution remains very limited. Adding an air gap and a glazing or plastic cover in front increases the temperature level of the useable heat, but decreases the power output manly due to higher refection losses. Such collectors may generate heat on the temperature level suitable for DHW whereas unglazed collectors may just preheat the water or work as heat source for a heat pump.

A major advantage of hybrid systems is the architectural harmony of solar power and solar thermal systems. This avoids to establish two technical systems with different appearance on a roof or façade. Hybrid collectors are still the subject of research and pilot applications [iea shc task 60].

solar
decathlon
europe

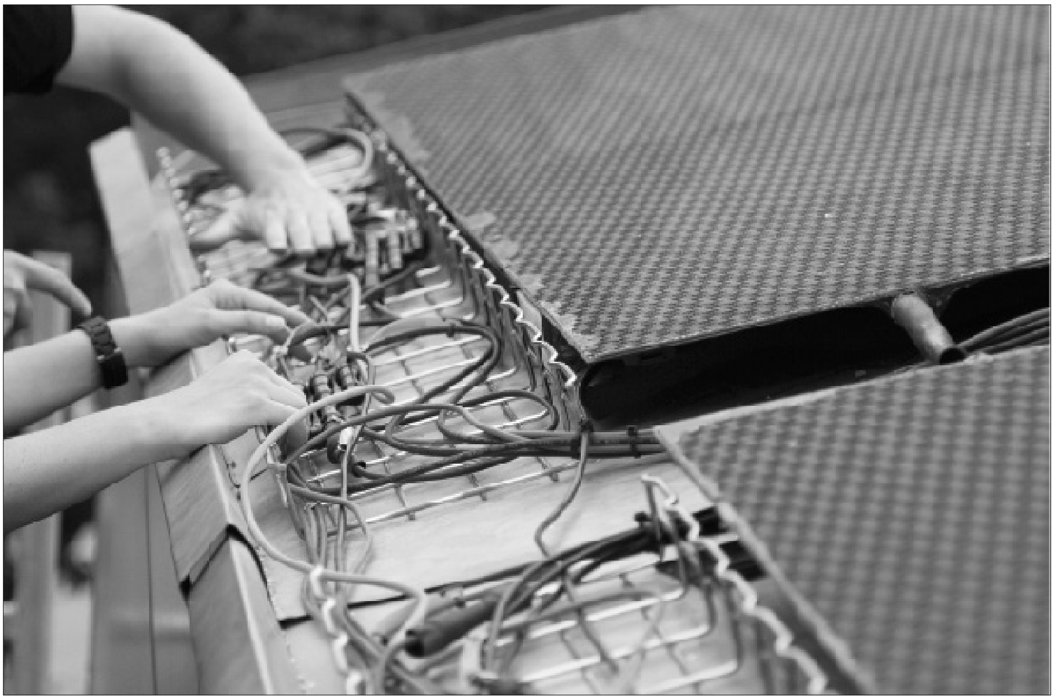


Figure 2.19: Custom developed PVT roof element from the 'Fold' house of the DTU Team in SDE12 during installation. Besides the wiring the picture shows the water pipe behind the panel responsible to transport the heat absorbed from the panel to the storage tank. Source: Danish Technical University DTU, SDE12, DTU Jury Report

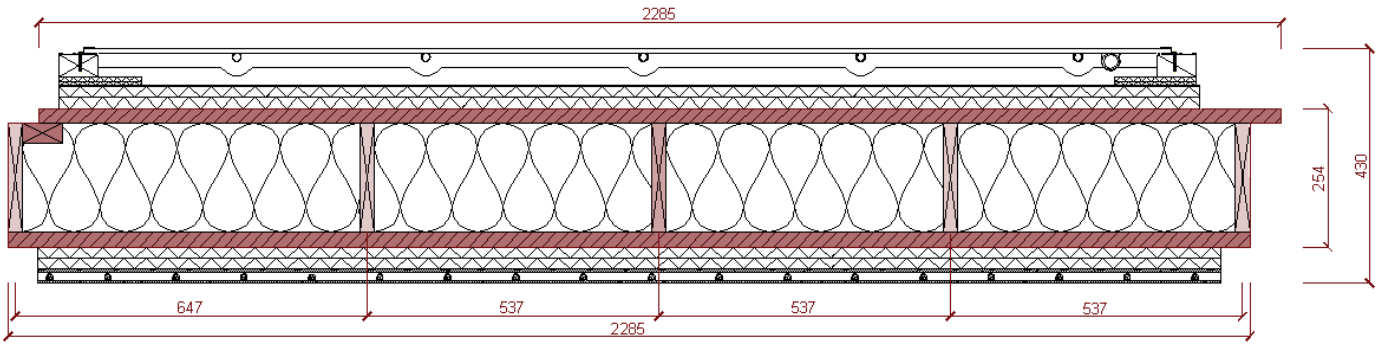



Figure 2.20: Cross section and installation of a PVT roof element from the 'Fold' house of the DTU Team in SDE12. Source: Danish Technical University DTU, SDE12, DTU Project Drawings

solar
decathlon
europe

Table 2.4: Solar thermal systems implemented in the SDE homes and associated properties.

Source: University of Wuppertal

CFA: conditioned floor area. The abbreviations of the team names are based on those used on the building competition knowledge platform.

| Edition | Team | Collector type | System location flat roof | Inclined roof | Facade | Other | System size $m^2$ | Storage volume litre | Conditioned floor area $m_{cfa}^2$ | Spec. collector area $m^2/m_{cfa}^2$ | Storage per collector area litre/$m^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | | | | | | | | | | | |
| | AMP | Hybrid Parabolic Concentrator | | 1 | | | | | 46,0 | | |
| | BER | Flat Plate Collector | | 1 | | | 8,4 | 450 | 52,8 | 0,16 | 54 |
| | BUW | Vacuum Tube Collector | | | 1 | | 6,0 | 250 | 48,6 | 0,12 | 42 |
| | CEU | Concentrating Collector + Hybrid PV | 1 | | | | | 200 | 50,8 | | |
| | GRE | none | | | | | | | | | |
| | HFT | Vacuum Tube Collector (+ Hybrid PV) | 1 | | | | 6,6 | 300 | 52,1 | 0,13 | 45 |
| | HUT | none | | | | | | | | | |
| | IAA | Hemisperical Solar Collector | | 1 | 1 | | 3,2 | | 57,4 | 0,06 | 0 |
| | TUC | Vacuum Tube Collector | | 1 | | | | 400 | 44,0 | | |
| | TUS | Vacuum Tube Collector + Hybrid PV | | 1 | 1 | | | 270 | 42,0 | | |
| | UDV | Vacuum Tube Collector | | 1 | | | | 200 | 46,4 | | |
| | UDS | Unglazed Flat Plate Collector | 1 | | | | | | 51,7 | | |
| | UOF | none | | | | | | | 46,0 | | |
| | UON | Flat plate | 1 | | | | 2,3 | | 72,0 | | 0 |
| | UPC | Flat Plate | | | 1 | | 6,9 | 290 | | | 42 |
| | VGT | none | | | | | | | | | |
| | Σ, Ø | | 4 | 6 | 4 | 0 | 5,6 | 295 | 50,8 | 0,12 | 53 |
| 2012 | | | | | | | | | | | |
| | ABC | Solar Thermal Concentrator | 1 | | | | 1,0 | 180 | 69,4 | 0,01 | |
| | AND | Flat Plate Hybrid | 1 | | | | 4,0 | 300 | 69,6 | 0,06 | 75 |
| | BME | Hybrid PV | 1 | | 1 | | | 150 | 45,0 | | |
| | BRA | Vacuum Tube Collector | | 1 | | | 5,4 | 300 | 55,6 | 0,10 | 55 |
| | BUC | Flat Plate | | 1 | | | 4,1 | 200 | 77,6 | 0,05 | 49 |
| | CEU | Vacuum Tube Collector | 1 | | | | 7,8 | 200 | 56,6 | 0,14 | 26 |
| | CUJ | Flat Plate | | | | 1 | 6,0 | 420 | 54,4 | 0,11 | 70 |
| | DTU | Hybrid PV | | 1 | | | 70,0 | 180 | 59,0 | 1,19 | 3 |
| | EHU | Flat Plate | 1 | | | | 2,2 | 110 | 49,1 | 0,04 | 50 |
| | FAU | Flat Plate | | 1 | | | 2,6 | | 49,2 | 0,05 | |
| | HTW | Hybrid PV | 1 | | | | 57,6 | 300 | 67,6 | 0,85 | 5 |
| | ROM | none | | | | | | | 55,5 | | |
| | RWT | Vacuum Tube Collector | 1 | | | | 13,0 | 400 | 61,8 | 0,21 | 31 |
| | STS | none | | | | | | | 58,2 | | |
| | TJU | Flat Plate Hybrid | 1 | | | | 6,4 | 400 | 61,6 | 0,10 | 63 |
| | TRA | Flat Plate Hybrid | 1 | | | | 13,0 | 180 | 68,8 | 0,19 | 14 |
| | UDZ | Flat Plate Hybrid | | 1 | | | 33,4 | 600 | 62,4 | 0,53 | |
| | UPC | Vacuum Tube Collector, Air Collector | | | 1 | | 4,0 | 400 | 45,5 | 0,09 | |
| | Σ, Ø | | 9 | 5 | 2 | 1 | 15,4 | 288 | 59,3 | 0,2 | 40 |

| Edition | Team | Collector type | System location flat roof | Inclined roof | Facade | Other | System size m² | Storage volume litre | Conditioned floor area $m_{cfa}^2$ | Spec. collector area $m^2/m_{cfa}^2$ | Storage per collector area litre/m² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | | | | | | | | | | | |
| | ATL | Flat plate | | 1 | | | 6,0 | | | | |
| | BAR | Flat plate | 1 | | | | 2,5 | 600 | 137,6 | 0,02 | 240 |
| | BUC | Vacuum Tube Collector | 1 | | | | 6,0 | 700 | 59,7 | 0,10 | 117 |
| | CUJ | Flat plate | 1 | | | | 6,0 | 420 | 75,7 | 0,08 | 70 |
| | DEL | Flat plate | | 1 | | | 5,4 | 300 | 85,0 | 0,06 | 56 |
| | DTU | Flat plate | | 1 | | | 4,4 | 180 | 66,5 | 0,07 | 41 |
| | FNX | Flat plate | | 1 | | | 2,4 | 150 | 52,9 | 0,05 | 63 |
| | INS | Vacuum Tube Collector | | | | 1 | 3,8 | 220 | 84,0 | 0,05 | 58 |
| | KMU | Vacuum Tube Collector | 1 | | | | 4,0 | 300 | 112,0 | 0,04 | 75 |
| | LUC | Vacuum Tube Collector | 1 | | | | 4,5 | 364 | 73,3 | 0,06 | 81 |
| | MEX | Vacuum Tube Collector | 1 | | | | 4,0 | 300 | 52,6 | 0,08 | 75 |
| | OTP | Vacuum Tube Collector | | 1 | | | 3,9 | | 110,0 | 0,04 | |
| | PAR | Flat plate | | | | 1 | 6,0 | 200 | 52,0 | 0,12 | 33 |
| | PLT | Flat plate | | 1 | | | 4,7 | 300 | 59,0 | 0,08 | 64 |
| | REC | Vacuuum tube, drain back | 1 | | | | 9,8 | 303 | 104,0 | 0,09 | 31 |
| | ROF | Vacuum Tube Collector | 1 | | | | 3,0 | 235 | 55,4 | 0,05 | 78 |
| | ROM | not specified | | 1 | | | 1,6 | 300 | 55,5 | 0,03 | 188 |
| | SHU | Vacuum tube, tank integrated | 1 | | | | 4,5 | 200 | 65,0 | 0,07 | 44 |
| | TEC | Flat plate | | 1 | | | 2,2 | 350 | 55,5 | 0,04 | 159 |
| | UNI | Vacuum Tube Collector | | 1 | | | 13,6 | 300 | 71,3 | 0,19 | 22 |
| | Σ, Ø | | 9 | 9 | 0 | 2 | 4,9 | 318 | 75,1 | 0,07 | 83 |
| | | | | | | | | | | | |
| 2019 | | | | | | | | | | | |
| | BUD | none | | | | | | | | | |
| | DEF | Flat Plate Hybrid | | | 1 | | 13,0 | | 51,0 | 0,25 | |
| | GUB | Flat Plate Hybrid | 1 | | | | | 260 | 69,2 | | |
| | KMU | Flat Plate | 1 | | | | 5,7 | | 62,5 | 0,09 | |
| | MIH | none | | | | | | | | | |
| | PLF | Vacuum Tube Collector | | | 1 | | | | 120,0 | | |
| | SEV | Vacuum Tube Collector | 1 | | | | 7,8 | 300 | 80,0 | 0,10 | 38 |
| | TUB | Flat plate absorber for a heat pump | | 1 | | | 1,6 | 250 | 65,0 | 0,02 | 156 |
| | UPC | none | | | | | | | | | |
| | VAL | Flat Plate Hybrid | | 1 | | | 5,0 | 220 | 54,2 | 0,09 | |
| | Σ, Ø | | 3 | 2 | 2 | 0 | 6,6 | 258 | 71,7 | 0,1 | 97 |

Figure 2.21: Concentration solar thermal system on the roof of a house at SDE10.
Source: K. Voss, University of Wuppertal

Figure 2.22: Façade-mounted flat plate collectors at a house at SDE14.
Source: K. Voss, University of Wuppertal

Figure 2.23: 6 m² vacuum tube collectors mounted vertically in an external wall of the BUW Team home at SDE10 in Madrid.
Source: K. Voss, University of Wuppertal

Figure 2.24: Vacuum tube collectors mounted in front of a window in the façade of the INHABITAT Team home at SDE19 in Szentendre. Besides hot water generation, the system allows some daylighting and generates shade to the window.
Source: K. Voss, University of Wuppertal


Figure 2.21


Figure 2.22


Figure 2.23


Figure 2.24

# 2.3 energy efficient devices & system concepts

### 2.3.1 Appliances

In the discipline, ‘house functioning’ refers to the houses' electrical energy consumption for household appliances, lighting, consumer electronics and other small appliances. There are also the evening events at which the Teams visit each other for dinner, requiring the additional operation of light and appliances. Household electricity consumption at SDE is usually higher than electricity consumption for heating, ventilation, cooling and domestic hot water (Figure 2.25). This is due in part to the moderate climatic conditions during the Competition periods in Europe (see Figure 2.1) and the additional use of ambient heat as the major heat source for the heat pumps beside electricity.

If we look at the scores in the energy contest, the houses have largely used highly energy-efficient appliances. Figure 2.26 shows the evaluation of the buildings' household electricity consumption at SDE14. The 2014 organiser was the first to introduce electricity recording by consumption sector. The average was 314 W; at the SDME in Dubai 2018, it was 450 W. Extrapolated over a whole year that is 2 750 kWh and 3 940 kWh respectively. In building practice, the standard figures per dwelling unit in Europe vary widely. This is because of the size of households (number of inhabitants) and different fittings/equipment and living habits. Statistics show values ranging from 1 000 kWh (Romania) to over 5 000 kWh (Sweden) [odyssee-mure 2020]. For the net zero energy and energy plus buildings implemented in Germany as part of the research initiative Effizienzhaus Plus, the averages for comparatively large single-family dwellings were 2.16 W per m² of living space [bmi 2018]. Taking into account the average living space of 78.3 m² at SDE14, the comparable figure is 4 W/m². The fact that the figure is much higher in terms of area for the houses at SDE is because they are fully fitted but have a small living space (see separate report on Building Design & Construction). This example shows the negative implications for energy consumption if the European trend towards smaller household sizes continues.

Nearly all Teams demonstrate very energy-efficient household appliances (Figure 2.27) and LED lighting in their buildings to reduce consumption and thus improve the energy balance (Figure 2.28). In some cases, special solutions were also used to replace the operation of equipment (e.g. dryers, Figure 2.30) or to substitute artificial light with daylight despite the lack of windows, Figure 2.29 [Frascarolo 2014].

solar
decathlon
europe

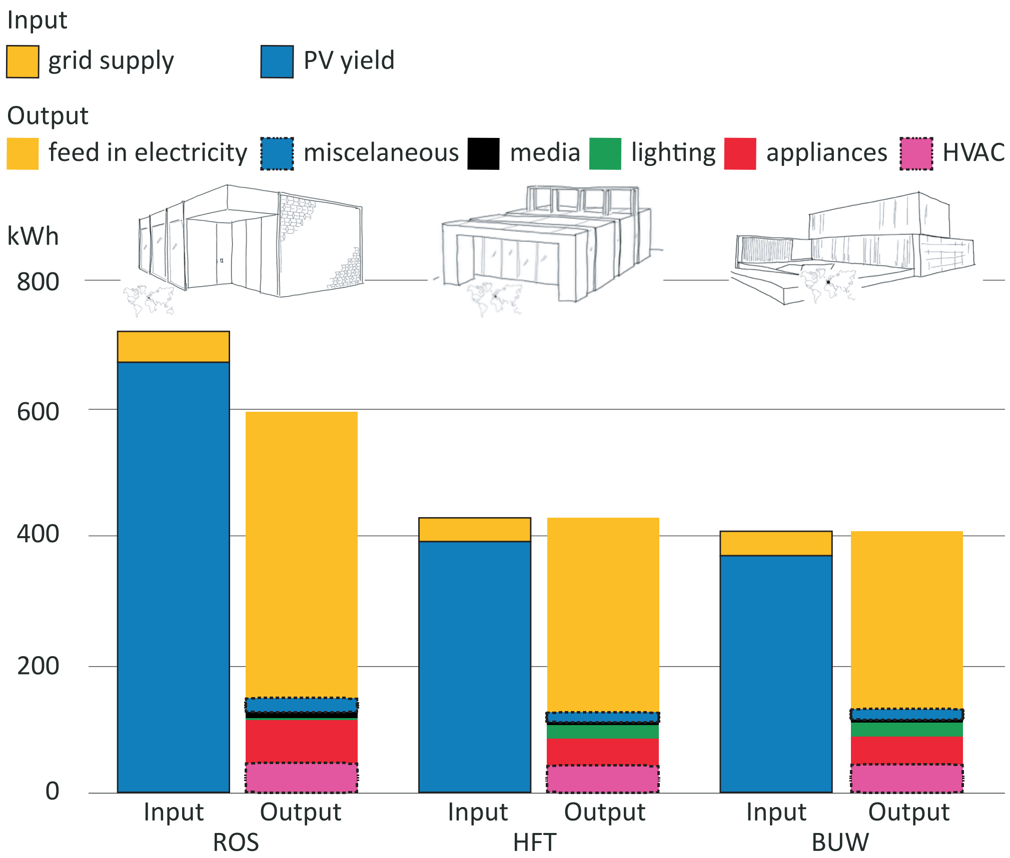



Figure 2.25: Measured energy consumption and energy generation of three SD houses. The figure shows the cumulative energy data of three German houses during the 10 event days of SDE10. Source: S. Hendel, University of Wuppertal

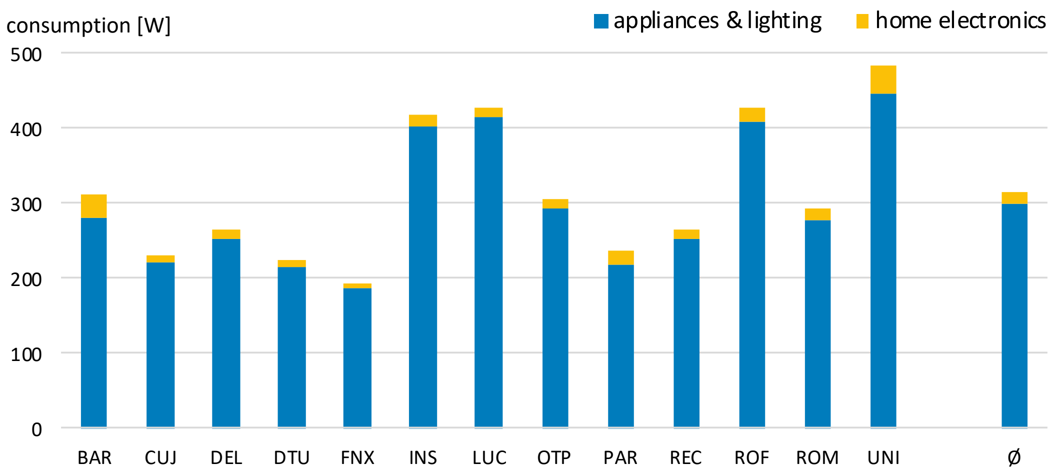



Figure 2.26: Average power for household appliances, lighting and small electrical appliances in the Competition period wat SDE14. Source: M. Stark, University of Wuppertal

solar decathlon europe

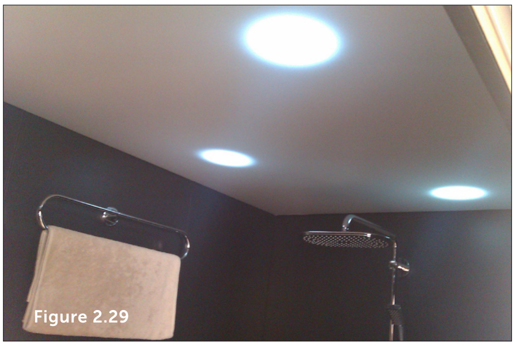


Figure 2.27: Example of the use of market available, energy-efficient appliances (SDE12).
Source: University of Wuppertal

Figure 2.28: Energy-efficient lighting by LED systems within an acoustic ceiling and integrated movement sensing (SDE10).
Source: University of Wuppertal

Figure 2.29: Daylight luminaires partly substitute artificial lighting in an internal bathroom (SDE12).
Source: University of Wuppertal

Figure 2.30: Integration of laundry drying in the circuit of the central ventilation system to substitute the operation of a dryer in the house of Team Lausanne at SD US 2017.
Source: University of Wuppertal

### 2.3.2 Heating, Ventilation, Air Conditioning and Domestic Hot Water (HVAC/DHW)

As all buildings at an SD are all-electric homes, all have heat pumps or compression refrigeration machines for active heating or cooling and for hot water. In the light of the growing use of renewable energies in the electricity grids of many European countries, the focus on electricity as energy source reflects a current trend. Heat pumps are increasingly becoming the standard supply option in new buildings and are replacing the decentralised combustion of fossil fuels such as natural gas. In some countries (Denmark), that combustion option has already been banned. The SDE houses and their energy concepts are therefore of great practical relevance in Europe. SDE21 for the first opens the energy supply side for other options within a real building energy concept (refer to section 2.5). The demonstration units must have no heat and cold supply unit. Due to the foreseen weather conditions during the Competition time, the houses are expected to run within comfortable indoor climate without active heating or cooling [sde21 2019].

solar
decathlon
europe

According to the heat transfer fluids used in the evaporator and condenser, the heat pumps used were categorized into groups such air-to-air heat pumps, air-to-water heat pumps, water-to-water heat pumps, water-to-air heat pumps, and other heat pumps. Using ground or ground water was no option within the Competitions, as Teams were not allowed to modify the ground of the lot. The Danish Team 'Fold' in SDE12 operates a buffer tank to 'simulate' the performance of a ground heat exchanger based heat pump system, Figure 2.31. In principle such systems are more effective (increased annual coefficient of performance due to more constant and more suitable temperature level of the source) but on the other hand it is more expensive to access the ground compared to ambient air. The lower investment is the major argument why ambient air heat pumps dominate the market.

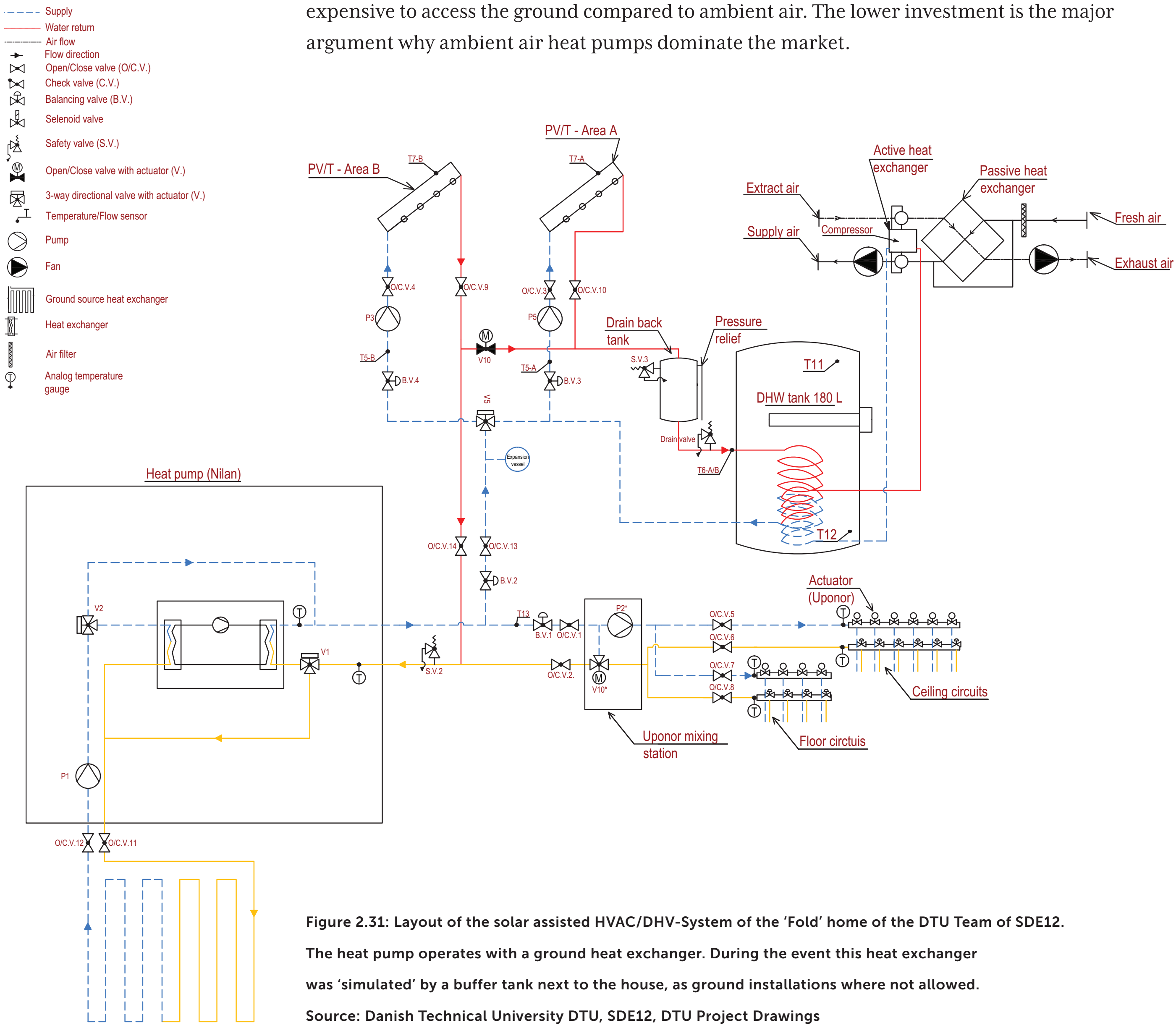



**Figure 2.31: Layout of the solar assisted HVAC/DHV-System of the 'Fold' home of the DTU Team of SDE12. The heat pump operates with a ground heat exchanger. During the event this heat exchanger was 'simulated' by a buffer tank next to the house, as ground installations where not allowed. Source: Danish Technical University DTU, SDE12, DTU Project Drawings**

solar
decathlon
europe

Either thermal solar systems or hybrid collectors are to be hydraulically integrated in line with the system concept. For reasons of necessary compactness, reversible units have generally been used, i.e. a single unit with both a heating and cooling function. The concepts implemented differ considerably: from combinations of standard units that are installed next to the buildings and supply the usual heating and cooling surfaces, to developments with a high degree of integration into the building ventilation system (compact ventilation units). The heat source in compact ventilation units is not outside air but instead the exhaust air after heat recovery from a mechanical ventilation system. In both concepts, the air is cooled to below the temperature of the outside air. For compact ventilation units, this means that the heat yield from the air flow must provide a sufficient heat source. This is usually only possible at the level of a passive house (space heating load max. 10 W/m²), which is not achieved by all SDE houses. The majority of SD buildings have a mechanical ventilation system, but not all.

Most heat pumps applied work with R410A as refrigerant. The Teams have chosen very different dimensioning for the units. Whilst a number of Teams work with compact units in a thermal power range of up to 2 kW, conventional split systems with almost 20 kW have also been used in the Competition. The average installed heating capacity in SDE12 was about 5 kW, Figure 2.32. In practice, units with higher power ratings allow the temperatures in the building to be adapted more quickly to requirements, but they also place a higher load on the power grid and are noisier and more expensive to purchase. At the 2021 European Competition, days for the measurement of the indoor climate will for the first time be consistently separated from those with visitor traffic in order to favour the use of smaller units.

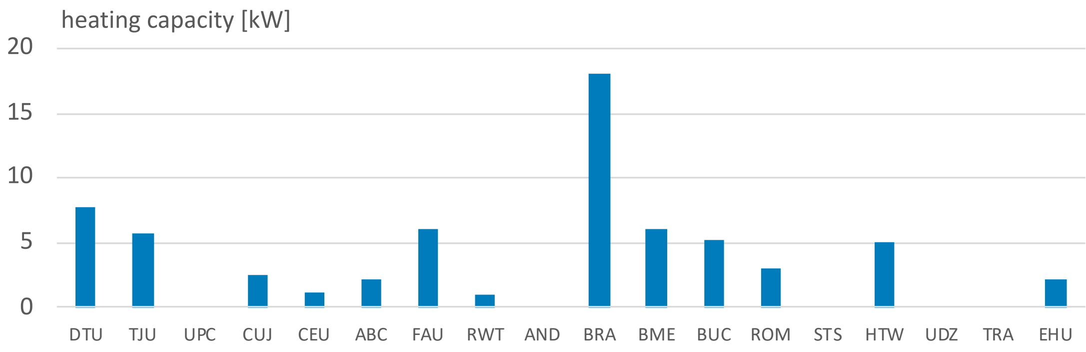



**Figure 2.32: Installed heating capacity of the heat pumps applied in SDE12 based on manufacturer data sheets. Data are not available for all Teams. Source: University Wuppertal**

The figures for electricity consumption for HVAC/DHW over the Competition period, using the example of SDE14, clearly show that it is not the building services engineering but rather household appliances that dominate consumption on locations with a moderate climate (see also section 2.3.1). The average for HVAC/DHW is 136 W compared to 314 W for household appliances. Unlike for the appliances, it is not possible to extrapolate annual consumption for the HVAC units as the climatic conditions on the Competition days do not represent the annual average.

solar
decathlon
europe

However, the annual figures calculated do also show that household appliances generally account for the largest proportion of demand. The use of solar thermal systems and efficient heat recovery from exhaust air to heat up the supply air are also contributing factors to lower the remaining electricity needs for HVAC/DHW. This finding shows how the scenario for buildings in Europe will change if integrated efficiency concepts are implemented. This becomes a different story with the Competition taking place in the Dubai climate as it was the case for SDME18. At that location the HVAC consumption made up half of the total consumption of about 1 000 W on average during the Competition period. This reflects the simulation findings presented earlier with Figure 2.1.

While air-to-air heat pumps in conjunction with ventilation units transfer heat directly to (heating) or absorb heat from (cooling) the indoor air, air-to-water heat pumps operate with heating or cooling surfaces so that the lowest possible temperature differences compared to the indoor air are sufficient for operation. To heat drinking water, air-to-air heat pumps must also supply an additional water circuit unless there is direct electrical heating of drinking water. The storage sizes selected for this purpose are in the range of 200 to 600 litres.


Figure 2.33: Split system compressor outside a building at SDE14.
Source: University of Wuppertal

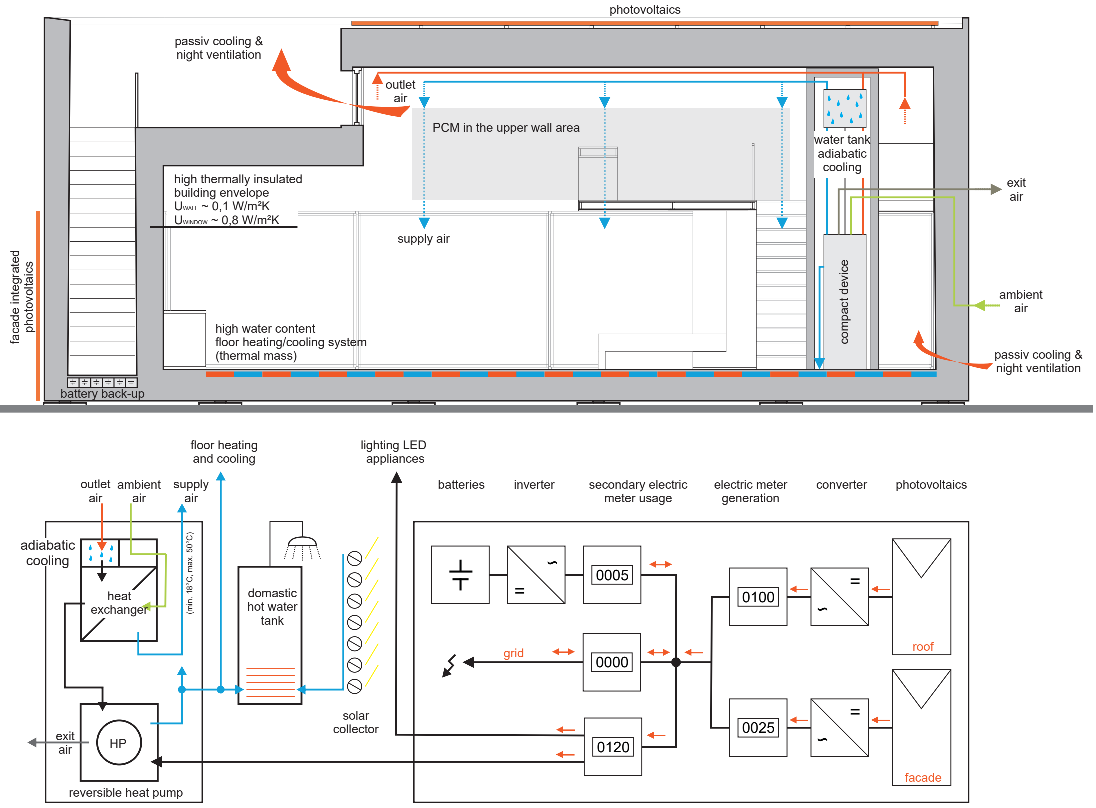



**Figure 2.34: Full integration of a compact device for HVAC and DHW in the SDE house by Team Wuppertal at SDE10. The compact unit takes the waste air after ventilation system heat recovery as a heat source for heating mode. Heat is delivered as switchable to the supply air, floor heating and the DHW storage tank. The compact unit is integrated into the house interior with acoustic insulation all around. The unit was, however, found to be too noisy in operation during the night when people are sleeping in the house. Source: University of Wuppertal**

For many buildings in moderate climates, domestic hot water will in practice determine how systems in nearly zero energy buildings and 'passive houses' are dimensioned. Whilst excellent heat and sun protection can keep heating and cooling capacities very low, and those requirements are usually met using large surfaces with small temperature differences to the indoor air, high temperatures are required for domestic hot water. For reasons of convenience and in line with the size of the storage tanks, water heating can therefore also result in high power consumption even over short periods of time. When operated for domestic hot water in particular, heat pumps have a comparatively poor coefficient of performance (ratio of heat output to electrical power consumption), which has a negative effect overall on the annual coefficient of production (ratio of annual heat yield to annual electricity consumption). The greater this effect, the greater the proportion of domestic hot water demand is in total heat demand. Solar collectors are therefore consistently used in many SDE buildings, as the right system design and operation in the Competition can render water heating with a heat pump almost completely unnecessary.
An IEA working group has researched and investigated such systems in depth in the light of their significant market relevance [iea shc task 44] [Herkel 2020].

solar
decathlon
europe

The performance of the heat pumps was not monitored in the Competitions up to now, but has partly been addressed in living labs of the participating universities following the Competition. Within the Competition, monitoring was limited to the power metering of the total HVAC circuit, but not in more detail than that. As already mentioned for the solar thermal systems, no heat output was monitored. No further performance analyses can be presented such as an investigation of the coefficient of performance in real operation compared to manufacturer data.

Even if there are no specific measurements to be evaluated for individual HVAC/DHW components, the houses in all SDE Competitions have implemented a wide range of innovations in this area, not least for single-family dwellings and small dwelling units, i.e. small-scale buildings:

- Ventilation heat recovery with high efficiency (> 85%)
- Direct and indirect evaporative cooling
- Advanced thermal storage with phase change material (PCM)
- Heat recovery from waste water
- $CO_2$-based heat pumps
- Absorption heat pumps
- Cooling ceilings with integrated PCM
- ...

The publication of Ma et.al. in the 2019 Journal of Cleaner Production presented a statistic overview on HVAC technologies applied in SD Competitions worldwide from 2002 to 2018 [ma 2019]. Table 2.5 extracts some of the analysis regarding the Competitions in Europe until 2014. The analysis in some points differs from own investigations due to unclear separation of topics. For example, the use of solar thermal for space heating may be partly not clearly separated from solar thermal use in general. Some PV systems are partly expanded to hybrid collectors and might be not listed as solar thermal applications. In general the publication underlines, that deep investigations regarding single technologies are not possible beside statistics. Testing and monitoring of technologies has not been part of the Solar Decathlon up to now. The evaluation of these innovations is the responsibility of the relevant jury, and subsequent monitoring ad development after the actual Competition is the responsibility of the Teams and their partners in industry.

Table 2.5: Statistical analysis of the HVAC technologies used in the SDE10/12/14 according to [ma 2019]

| | Solar thermal space heating | Radiative cooling | Evaporative cooling | Desiccant dehumidification | Absorption/ adsorption cooling | Phase change material | Ventilation heat recovery | Radiant heating | Radiant cooling |
|---|---|---|---|---|---|---|---|---|---|
| SDE 2010 | 41% | 18% | 29% | 0% | 6% | 53% | 77% | 53% | 59% |
| SDE 2012 | 50% | 33% | 22% | 11% | 6% | 44% | 78% | 39% | 33% |
| SDE 2014 | 65% | 5% | 15% | 10% | 0% | 50% | 90% | 40% | 35% |
| | Heating & cooling Technologies | | | | | Storage | Recovery | Delivering method | |

solar
decathlon
europe

Two practical aspects at the SDE Competitions also illustrate the challenge of using heat pumps:

- Dense building development on the Competition site focuses visitors' attention on noise emissions from the systems or system components installed there. Outside-air heat pumps and chillers outside in dense housing developments are in practice often at the centre of neighbourhood disputes when not dimensioned appropriately. This is particularly true when high system or unit output is required.
- Where heat pumps are installed inside the SD buildings, for example as compact ventilation units, this clearly shows the problems of noise emissions when there are nearby bedrooms. In some cases, such problems pose limits on compact floor plans. In practice, separate, sound-insulated technical rooms and special measures to reduce the transmission of equipment noise around the installation area and the air ducts are required.

Both aspects are included in SDE as part of the jury evaluation for 'Engineering & Construction'. Measurements of equipment noise have been addressed in the Rules for individual Competitions, but not conducted or documented in practice.

An overview of innovations at the American Competitions up to 2015 was presented in 2017 [nrel 2017]. The summary states that:

"While the Solar Decathlon does not explicitly work to invent new technologies or solutions, Teams have shown a willingness to adopt and experiment with new solutions years ahead of the general industry. Over time, the technologies developed, demonstrated, and perfected for the Competition series have become more commonplace in industry. Examples include:

- All-electric heat pump water heaters;
- Modular and factory-standardized housing approaches;
- High-efficiency and small-space HVAC solutions;
- Smart home and consumer-focused home control systems;
- Whole-house packaged comfort systems providing space heating and cooling, indoor air quality, and water heating."

solar
decathlon
europe

Figure 2.35: Service room with heat pump and thermal storage in an SDE house in 2010 in Madrid.
Source: University of Wuppertal

Figure 2.36: Visible installed ventilation components above the windows – internal components of a split system at SDE14.
Source: University of Wuppertal

Figure 2.37: Mobile, planted duct to increase humidity in the dry summer climate in Madrid, SDE12, without active air conditioning.
Source: University of Wuppertal

Figure 2.38: Planted wall to increase humidity in the dry summer climate in Madrid, SDE10 without active air conditioning.
Source: University of Wuppertal


Figure 2.35


Figure 2.36


Figure 2.37


Figure 2.38

solar
decathlon
europe

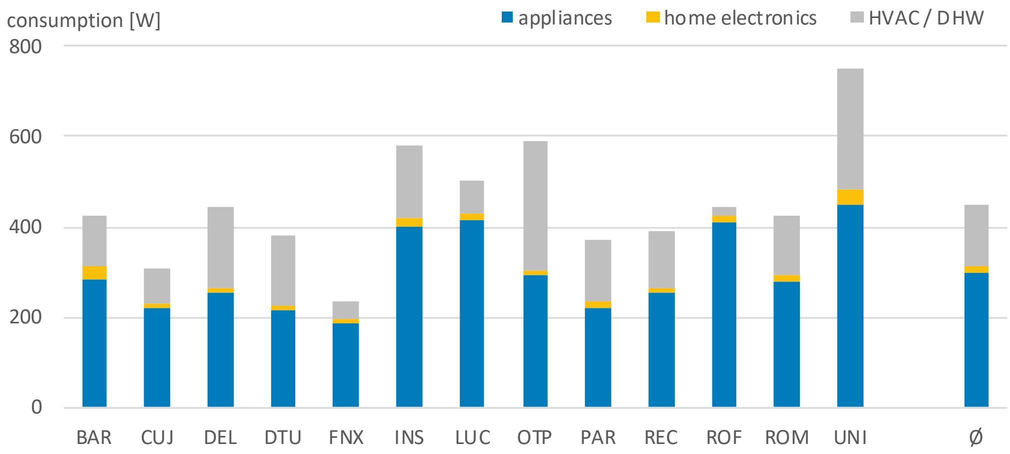



**Figure 2.39: Average power consumption in the circuit for the HVAC and DHW systems compared to other loads of all houses during the Competition period at SDE14. In all cases, the appliances dominate the energy consumption. Source: M. Stark, University of Wuppertal**

### 2.3.3 Controls

In most SDE houses, buttons and touch-panel operation have replaced the usual switches and controls. Various types of bus systems such as knx and EIB and wireless communication systems in conjunction with smart home systems are also used. These solutions have regularly sparked huge visitor interest as they are a contrast to familiar controls in building practice. Market penetration in Europe is still comparatively low. SDE21 will for the first time evaluate the user-friendliness of such interfaces as part of the Competition. Guest Teams will evaluate user-friendliness at evening events in the buildings using questionnaires and interviews [sde21 2019].

Smart home system functions go far beyond energy and indoor climate management: billing, convenience, security, home entertainment, independence and social participation in old age, etc. However, specific examples from SDE relating to energy and room climate management include:

- Shared use of available information about the outdoor climate, the indoor climate, the operating states of technical systems and storage availability for energy-optimised system management.
- Daylight measurement and presence monitoring for lighting control
- Energy-saving control of air volume based on $CO_2$ measurement and targets.
- Information for users to facilitate energy-saving behaviour.
- Operation of devices over a standard interface.
- Integration of weather forecasts, simulation models and decision algorithms from neural networks into system controls.
- Consideration of energy consumption forecasts based on adaptive algorithms for user behaviour such as arrival times, periods at home and consumption peaks
- Flexible building-grid interaction: using information on the state of the public grid to decide on the operation of systems and storage systems. Electricity should if possible be purchased when it is available $CO_2$-free and if possible not when it involves high emissions [iea annex 67].

solar decathlon europe

The use of smart controls involves additional consumption by the controllers themselves. This is of particular significance when it comes to controlling small levels of consumption – which is frequently the case in SDE buildings. In some cases, Teams therefore use controls they have developed themselves on the basis of low-power components (e.g. Raspberry Pi...). Such innovations offer inspirations for the professional equipment market.

Figure 2.40

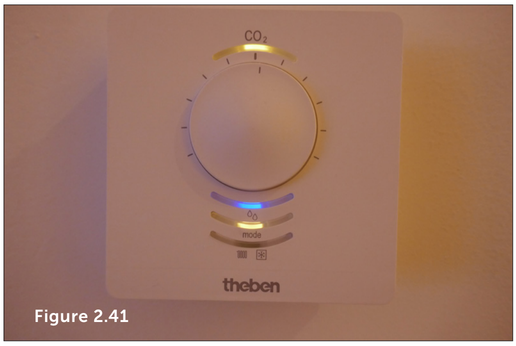



Figure 2.41

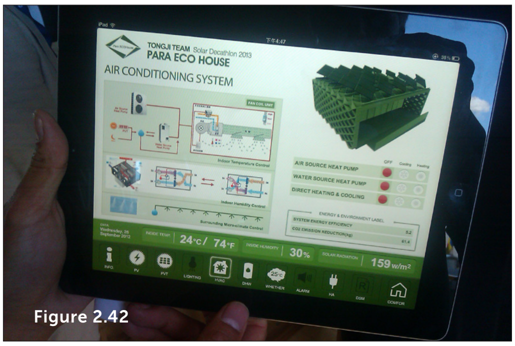



Figure 2.42


Figure 2.43

Figure 2.40: Typical low-voltage pushbuttons as part of the building automation system to replace classical switches for AC wiring (SDE12).
Source: University of Wuppertal

Figure 2.41: Turning knob to manually adjust the set point for a $CO_2$-controlled ventilation system (SDME 2018).
Source: University of Wuppertal

Figure 2.42: User interface for operating the HVAC system in the Tongji Team house at SDE12.
Source: University of Wuppertal

Figure 2.43: Graphic display of the building automation system for the Baitycool Team at SDME 2018 in Dubai.
Source: University of Wuppertal

Assisting the manual control by the occupants with a suitable automatic control of solar shading and ventilation is a key issue to run a building with convincing thermal comfort, indoor air quality and low energy consumption. Summer thermal comfort is a key issue with regard to climate change [arranz 2014]. Indoor air quality becomes a challenge for buildings with almost air tight envelopes. SDE Rules specially address both issues since the beginning. The following two figures illustrate monitoring results for indoor comfort for selected buildings of SDE10. The challenge for the Teams was the combination of visiting periods without scoring followed by scored periods during the same days.  Large installed cooling, heating or even ventilation capacity was favourable to control the temperature quickly after visiting times to the required conditions for the following monitoring period. The challenge was particularly high for the most attractive houses visited by many people. SDE21 plans an event schedule with full separation of scored days for indoor comfort measurements and visiting days.

solar
decathlon
europe

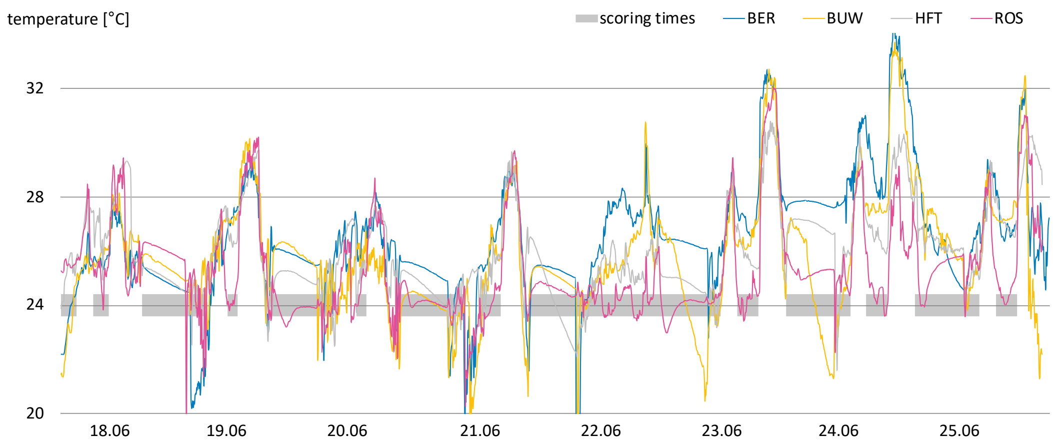



Figure 2.44: Example of transient indoor air temperature of four houses at SDE10. The grey bars mark the times when scoring takes place. Full points are gain for keeping the temperatures between 23°C and 25°C, reduced points up to 27°C or down to 21°C. It was the task of the controls to operate the building in such a way as to maximizing the score. Large installed cooling or heating capacity was favourable to control the temperature quickly after visiting times to the required conditions for the monitoring period. Source: University of Wuppertal

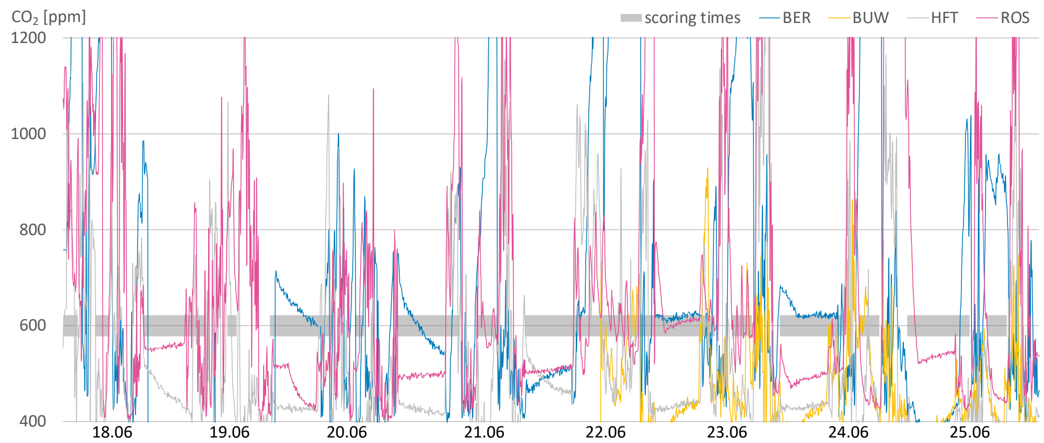



Figure 2.45: Example of transient indoor air quality ($CO_2$) measurements of four houses at SDE10. The sensor in the house of Team BUW shows wrong results in the early days. Comparable to the figure before the grey bars mark the times when scoring takes place. Full points are gain for keeping the CO2 level below 800 ppm, no points above 1,200 ppm. It was the task of the controls to operate the ventilation in such a way as to maximizing the score. Source: University of Wuppertal

solar
decathlon
europe

## 2.4 energy balance & building grid interaction

SDE houses should demonstrate how to balance out electrical consumption through solar power generation (net zero-energy buildings) and ideally also generate significant surpluses for grid feed-in (net energy plus buildings). An evaluation of monitoring data during the Competition period shows whether or not this has been achieved. The graphs below (Figure 2.44 and Figure 2.45) chart total generation and consumption during the Competition period for all buildings in the two Competitions in 2010 and 2014. Details for SDE12 have been published in a special issue of the Energy and Buildings journal [Rodriguez-Ubinas 2014].

As Figure 2.44 explains, all buildings at SDE10 achieved a positive energy balance. This was due in part to favourable climatic conditions – lots of sunshine – during the Competition period and to the size of the PV systems (up to 15 kWp). Limiting the size to a maximum of 5 kWp significantly changes the balance at SDE14. As a result, not all houses achieve a positive balance although the electricity consumption is similar (N.B. scaling is different). Monitoring was more extensive at SDE14 and the feed-in and consumption balance is therefore also shown. The difference is the houses' own consumption of solar power they generate. Where one dot is directly above another (same consumption), the two relate to the same building. The distance between them indicates how well that house is covering its own demand. Buildings with batteries and intelligent control are at an advantage here (section 2.3.3). For small single-family dwellings with heat pumps and photovoltaic systems without battery storage, the self-consumption rate in practice is about 20 to 40 % for the year as a whole [bmi 2018]. The main reason why the rate is not higher is that large solar energy systems are required to balance out electricity consumption for the year overall. Large systems lead to large surpluses on sunny days, in particular during the summer months. At SDE14, the average self-consumption of self-generated solar electricity is 37 % with a range from 25 to almost 60 %. High figures represent buildings with comparatively small solar power systems, systems with different orientations or angles per house, battery storage and good energy management.

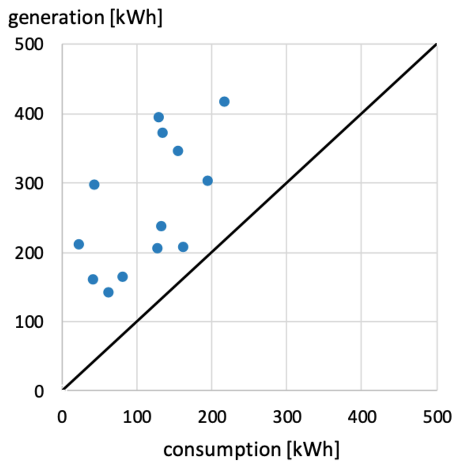



Figure 2.46

Figure 2.46: Electrical energy balance of all houses at SDE10 based on monitored data during the Competition period. Houses with data points above the diagonal are energy plus homes: the generated power of all houses exceeds the consumption. Source: M. Stark, University of Wuppertal

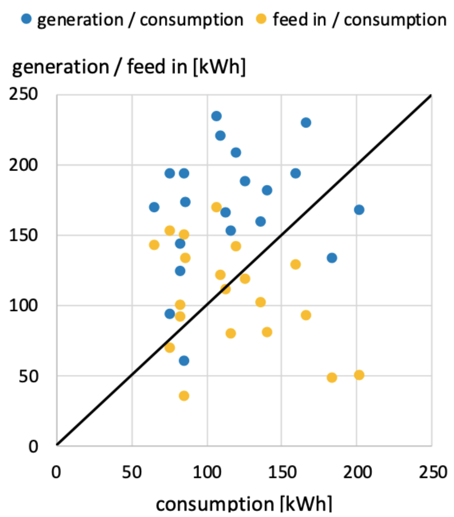



Figure 2.47

Figure 2.47: Electrical energy balance of all houses at SDE14 based on monitored data during the Competition period. Besides the generation / consumption balance, the diagram shows the feed-in / consumption balance. Please note the change in the scaling compared to Figure 2.46. Source: M. Stark, University of Wuppertal

solar
decathlon
europe

Figure 2.48 shows the superposition of electricity loads and electricity generation of all houses for SDE14. It shows the electricity profile over time for the entire solar village. The graph clearly shows the feed-in peaks of around 50 kW in the middle of the day on sunny days and evening peak loads of 25 kW. The evening peak loads can be considerably reduced by in-house battery storage, but clearly not completely balanced out. Feed-in to the batteries in the morning delays high feed-in until the batteries are recharged. In a development made up of houses with heat pumps (refrigeration machines) and heat accumulators (cold accumulators), controls could ensure that units did not start up at the same time. Such 'intelligent control' on a district scale can balance the grid profile, reducing the load on necessary grid expansion in new housing developments.

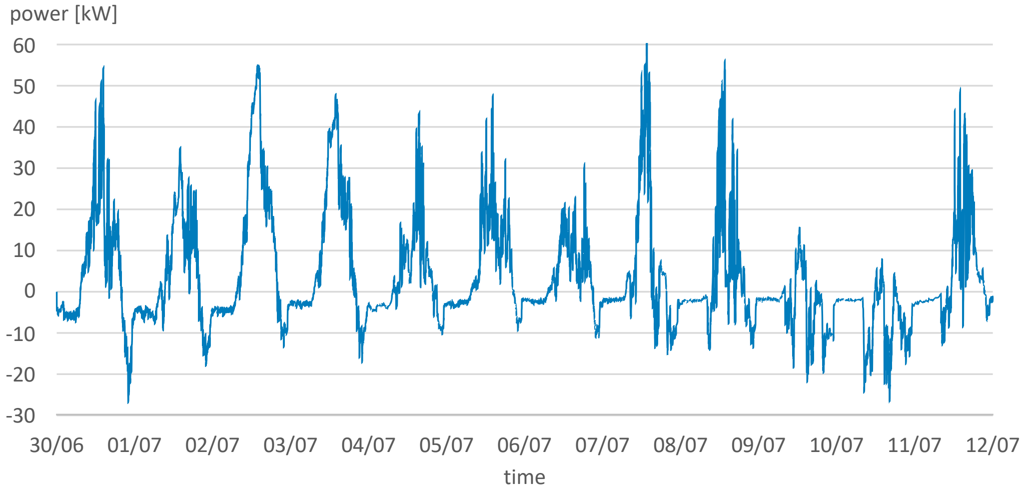



**Figure 2.48: Superposition of the electric load and generation for all houses at SDE14. Negative numbers correlate to a load greater than the generation. This illustrates the transient status of the 'solar village' grid. Source: M. Stark, University of Wuppertal**

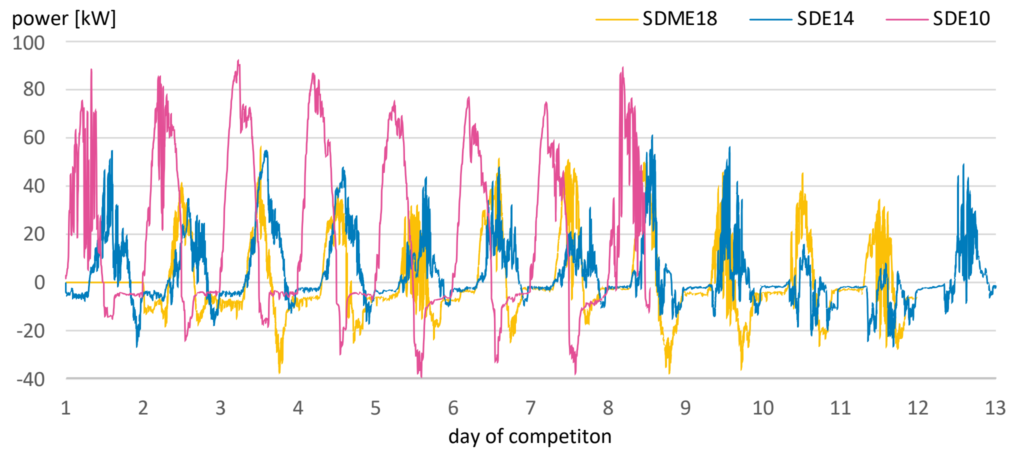



**Figure 2.49: Superposition of the electric load and generation for all houses at SDE10 and SDE14 together with data from the SDME in Dubai 2018. Data for SDE10 are only available for 8 days. Please note that the diagram compares the power balance from different Competitions with different climates and different Rules. Source: M. Stark, University of Wuppertal**

solar
decathlon
europe

Figure 2.50: Typical grid access point at SDE14.
Source: University of Wuppertal

Figure 2.51: Small electric car with charging point as part of the houses' energy concept at SDE12.
Source: University of Wuppertal

Figure 2.50

Figure 2.51

Typical indicators for the analysis of the dynamic performance of solar powered homes are:

- Self-consumption: The ratio of the solar yield instantaneously used to cover the load in the house or stored in a battery. 100% indicates that all the solar yield is directly used and no electricity is fed into the public grid. This is the case for small installations in houses with high and continues consumption.

- Self-sufficiency: The part of the load that is instantaneously covered by the solar yield or the battery.
(Note: In this interpretation the battery should not be used to buffer power from the grid).
100% indicates that the solar system always generates at least the power needed in the house. As this is not possible during night, battery storage is a precondition.

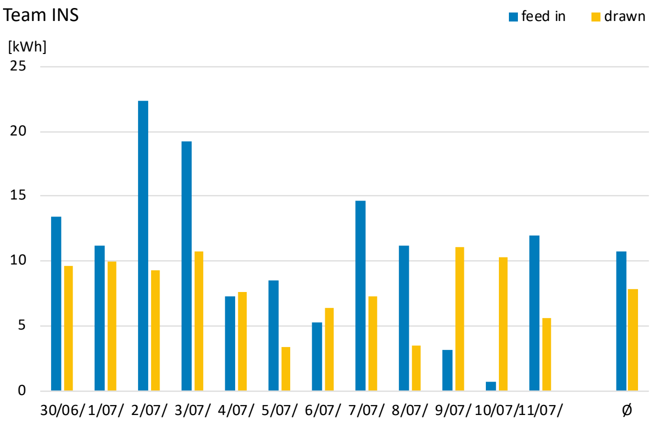
Both indicators are sensitive to the data resolution. Real numbers are direct meter readings. Due to the monitoring concepts and the available resolution of the meter readings, the indicators for the SDE homes can only be calculated based on one-minute resolution data, thereby documenting slightly higher indicators as real. Nevertheless, the following diagrams illustrate the advantage of battery storage with the example of the Team OTP house in SDE14 (capacity 5 kWh) compared to the house of the Team INS, not equipped with battery storage. Resulting from internal storage less electricity is distributed to and drawn from the grid. Averaged over the Competition period the degree of self-sufficiency is nearly doubled and the self-consumption increases by 60%. On the other hand, such results cannot be generalized as positive under today's circumstances: As every form of storage creates losses it is in many cases better to feed excess power into the grid and consume it in a house in the neighborhood as long as the majority of houses don't have solar power supply. The SD houses with battery storage anticipate a future with a much higher penetration of solar energy utilization in buildings as today!

solar
decathlon
europe

Figure 2.52: The Team INS 'Inside Out' house from SDE14. Source: K. Voss, University of Wuppertal

Figure 2.53: The OTP 'On Top' house from SDE14. Source: K. Voss, University of Wuppertal





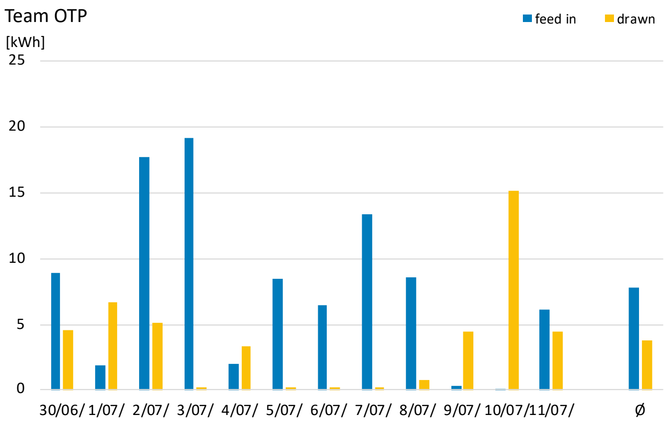
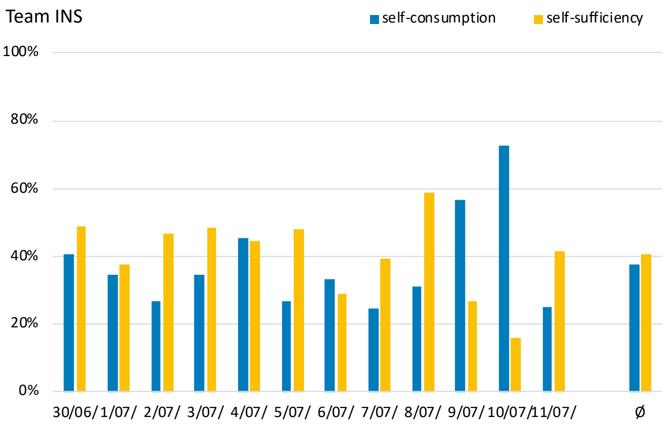




Figure 2.54: Comparison of the energy drawn from and energy feed into the power grid for two example buildings of SDE14. The OTP house (right diagram) uses a battery storage with a capacity of 5 kWh. Source: M. Stark, University of Wuppertal



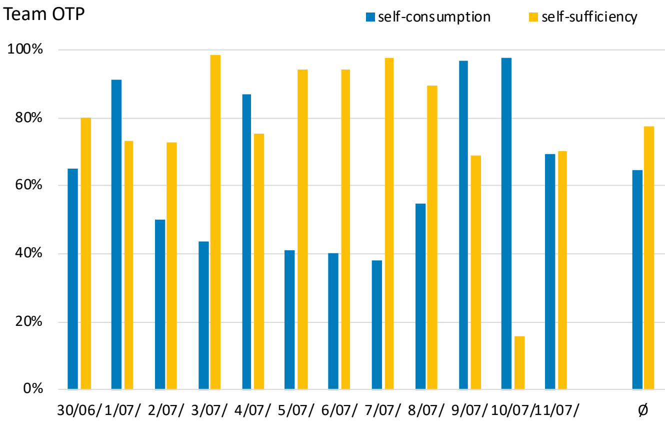




Figure 2.55: Comparison of the indicators for self-consumption and self-sufficiency for two example buildings of SDE14. The OTP house (right diagram) uses a battery storage with a capacity of 5 kWh resulting in significantly increased indicators. Source: M. Stark, University of Wuppertal

solar
decathlon
europe

In addition to the energy balance and self-consumption rates, the SDE21 Rules provide special tasks to improve and explore energy flexibility of buildings:

- Teams are individually requested a day ahead to provide increased feed-in of solar power to the grid. This task will address increased feed-in in the morning by demand-side management of power consumption and/or reduced charging of a battery system (if installed).
- Each Team receives an individual day-ahead forecast of the Solar Campus grid's electricity price function. This price function results from an assumed $CO_2$ content of the generated power in the grid. A low $CO_2$ content results from power generation based on renewables. The task is to recognise and utilise the most favourable consumption strategy on the basis of demand-side management and (if installed) prioritises the use of battery-stored solar power.

Future Competitions might even more address energy flexibility as an important issue. Aspects such as how to level out demand, generation and storage beneficial for the sizing and function of the electricity network are to be addressed [iea ebc annex 67]. Research in the framework of SDE12 has addressed such topics using the solar village as a case study [li 2019].

solar
decathlon
europe

# 2.5 outlook

The Competitions in Europe have shown a remarkable evolution over the past ten years with a variety of modifications resulting from lessons learned.

To date, the analyses of the energy systems at SDE has been mainly limited to the houses energy consumption and energy yield of the solar power systems. The considerable time and expense that go into developing and constructing the buildings raises the question of an advanced monitoring concept for subsystems such as the heat pumps, the thermal solar systems and the ventilation systems. SDE14 had already introduced a systematic breakdown on the consumption side. In 2021, detailed measurements for photovoltaics are also to be added (performance ratio). There will, for the first time, also be a comparison of simulation and measurement on three trial days before the actual Competition (performance gap). This will establish what findings can be obtained and the effort and investment involved.

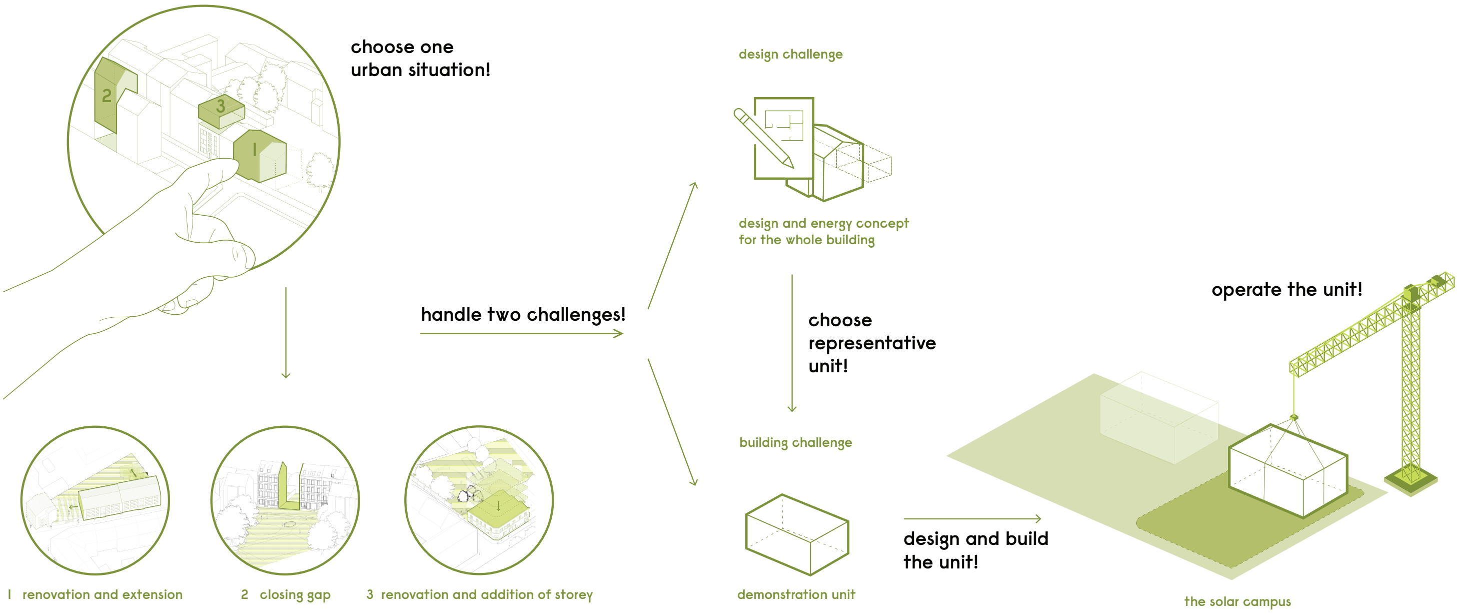
In many areas, SDE has identified and identifies innovations in the field of energy systems for which a detailed quantitative assessment has not yet been possible within the framework of the Competition. It remains the role of the Teams to pursue these questions after the Competition by working on their houses at their permanent locations. Many Teams have done so in the past, operating the buildings as living labs at their universities. At SDE19, in Morocco 2019 and indeed in Dubai at SDME18, some buildings were for the first time able to remain on the Competition site, as the Competition sites were part of research centres. This has benefits for subsequent research. In the case of SDE19 and SDME18 it had a very negative impact on visitor numbers. It remains to be seen what work will be done with the houses at these sites. The potential for scientific work is certainly there. Another advantage of buildings remaining on the site is that it allows systematic commissioning and adjustment to achieve improved results in subsequent measurements. This is a major shortcoming in the actual Competition profile, as there is not enough time for it. Unlike in practice, the houses must function perfectly immediately after construction. For buildings that remain in place, systematic, scientific tests can be carried out at a building level (co-heating tests) and at a component level (dynamic U-value testing, COP analysis …  [iea ebc annex 71]). As a rule, however, the buildings then remain uninhabited, as living on test sites is not permitted under local building law. This is the advantage of the Teams' living labs at their home locations, as different building regulations apply outside the test sites.

Considering the amount of limitations for energy systems and research given by the fact of a common event site, a decentral Competition throughout Europe might be an option for further investigations. It allows to keep the triple of ‘design-build-operate’ but widen the scope of possible energy engineering with respect to the given sites. An example for such a concept was the Oman Eco House Competition in 2014 with five different buildings on different sites in the country [oman 2014]. The US Solar Decathlon for 2022 is also planning in that direction.

solar
decathlon
europe

Some Teams at previous SDE Competitions had already decided to produce their entry in the context of a real construction task and site. The energy concept thus reflected not only the best fit with the Rules of the Competition, but also with that specific site and task. This is not an easy balancing act. SDE21 specifies further development as multi-storey residential buildings. Energy concepts for real construction tasks are to be developed. The house on the Competition site represents only part of that task. A few Teams in earlier Competitions decided themselves to take on such challenges. SDE21 is, however, the first edition at which the jury will consider the energy concept for the building as a whole and not just that of the demonstration building at the Competition [sde21 2019]. The focus on electricity as the sole power source no longer applies for the complete buildings. However, this criterion still holds for the demonstration buildings on the Competition site. Considering a fully decentral Competition would overcome such limits. It may strengthen the reality lab character by respecting the site context in architecture as well as in engineering and opens the floor for R&D with the building after the event phase. Of course the event character would fully change and the communication and social awareness strategy would become a fully new task to design and work with.

Figure 2.56: The call for Teams for SDE21 illustrates the intension to put the demonstration units on the Competition site in the context of real urban further building. Teams have to develop energy concepts for the building in an urban context and have to transfer the approach into the demonstration unit.
Source: University of Wuppertal



solar
decathlon
europe

## References


* **[arranz 2014]** Beatriz Arranz, Edwin Rodríguez, César Bedoya, Sergio Vega: Evaluation of three solar and daylighting control systems based on CalumenII, Ecotect and Radiance simulation programs to obtain an energy efficient and healthy interior in the experimental building prototype SDE10, Energy and Buildings, Volume: 83, pp. 225-236, 2014
* **[bmi 2018]** Wege zum Effizienzhaus Plus - Grundlagen und Beispiele für energieerzeugende Gebäude, German Federal Ministry of Interior, Building & Community, 2018, https://www.bmi.bund.de/SharedDocs/downloads/DE/publikationen/themen/bauen/effizienzhaus-plus.pdf?__blob=publicationFile&v=6
* **[cronemberger 2014]** Joara Cronemberger, Monica Almagro Corpas, Isabel Cerón, Estefanía Caamaño-Martín, Sergio Vega Sánchez: BIPV technology application: Highlighting advances, tendencies and solutions through Solar Decathlon Europe houses, Energy and Buildings Volume 83, pp. 44-56, 2014
* **[county 2020-1]** County, P., Boesiger, M., Bacher, J.-P.: Photovoltaics, Topical Paper of IEA EBC Annex 74, download in the section of teaching material in the knowledge platform, https://building-competition.org/
* **[county 2020-2]** County, P., Torregrossa, D., Bacher, J.-P.: Battery Storage Systems for Building Applications, Topical Paper of IEA EBC Annex 74, download in the section of teaching material in the knowledge platform, https://building-competition.org/
* **[detail 2011]** Solararchitektur 4 – Die deutschen Beiträge zum Solar Decathlon Europe 2010, Detail Verlag, München, 2010, ISBN 978-3-920034-48-5
* **[energy charts 2020]** Fraunhofer ISE, Energy Charts, https://www.energy-charts.de/power.htm
* **[eurostat 2019]** The average share of electricity from renewable energy sources in the EU, European Commission Eurostat, Directorate E: Sectoral and regional statistics Unit E.5: Energy, 2019, https://ec.europa.eu/eurostat/documents/38154/4956088/The+average+share+of+electricity+from+renewable+energy+sources+in+the+EU+%282004-2017%29/19a0f4a7-8770-48c7-978d-693833a37546
* **[frascarolo 2014]** Frascarolo, M., et. al.: An innovative lighting system for residential application that optimizes visual comfort and conserves energy for different user needs, Energy in Buildings, volume 83, 2014, pp. 217-224, https://www.sciencedirect.com/journal/energy-and-buildings/vol/83/suppl/C
* **[garcía-domingo 2014]** Garcia-Domingo, B. et. al.: Design of the back-up system in Patio 2.12 photovoltaic installation, Energy in Buildings, volume 83, 2014, pp. 130-139, https://www.sciencedirect.com/journal/energy-and-buildings/vol/83/suppl/C
* **[haeberle 2020]** Haeberle, A.: Solar Thermal Systems, Topical Paper of IEA EBC Annex 74, download in the section of teaching material in the knowledge platform, https://building-competition.org/
* **[herkel 2020]** Herkel, S.: Heat Pumps, Topical Paper of IEA EBC Annex 74, download in the section of teaching material in the knowledge platform https://building-competition.org/
* **[iea ebc annex 67]** Energy Flexibility, International Energy Agency, Energy in Buildings and Community Systems Programme, http://www.annex67.org/publications/
* **[iea ebc Annex 71]** Building Energy Performance Assessment Based on In-situ Measurements, International Energy Agency, Energy in Buildings and Community Systems Programme, https://www.iea-ebc.org/projects/project?AnnexID=71
* **[iea shc 2019]** Weiss, W., Spork-Dürr, M.: Solar Heat World Wide, Edition 2019, International Energy Agency, Solar Heating & Cooling Programme, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2019.pdf
* **[iea shc task 44]** Solar and Heat pump Systems, International Energy Agency, Solar Heating & Cooling Programme, https://task44.iea-shc.org/publications
* **[iea shc task 60]** PVT Systems-Application of PVT Collectors and New Solutions in HVAC Systems, International Energy Agency, Solar Heating & Cooling Programme, https://task60.iea-shc.org/
* **[li 2019]** Li, Y., García-Castro, R., Mihindukulasooriya, N., O'Donnell, J., Vega-Sánchez, S.: Enhancing energy management at district and building levels via an EM-KPI ontology, Automation in Construction Volume: 99, pp. 152-167, 2019

* **[ma 2019]** Ma, Z., Ren, H., Lin, W.: A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses, Journal of Cleaner Production, 240, 2019
* **[nrel 2017]** Simon, J., Doris, E., Farrar, S.: Insights on Technology Innovation – A Review of the U.S. Department of Energy Solar Decathlon Competition Entries 2002–2015, Technical Report, National Renewable Energy Laboratory, Golden, USA, 2017
* **[odyssey-mure 2020]** https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling-electrical-appliances-lighting.html
* **[oman 2014]** The Oman Eco House Design Competition 2014, https://omanecohouse.livetozero.com/
[rodriguez-ubinas 2014] Rodriguez-Ubinas, E., et. al.: Energy efficiency evaluation of zero energy houses, Energy in Buildings, volume 83, 2014, pp. 23-35, https://www.sciencedirect.com/journal/energy-and-buildings/vol/83/suppl/C
* **[sartori 2011]** Sartori, I.; Napolitano, A.; Voss, K.: Net Zero Energy Buildings: A Consistent Definition Framework. Energy and Buildings, Elsevier, Oxford, 2011
* **[sde flickr]** free picture album of Solar Decathlon Europe, https://www.flickr.com/photos/sdeurope/?utm_medium=website&utm_source=archdaily.co
* **[simroom 2020]** SimRoom – A dynamic single zone building simulation tool for educational use, Markus Lichtmess, 2020, https://www.enec.de/page/SimRoom/index.html
* **[sde21 2019]** Rules and Site Description for the Solar Decathlon Europe 2021, https://sde21.eu/competition/documents
* **[voss 2011]** Voss, K. Musall, E. (ed.): Net Zero Energy Buildings - International Projects on Carbon Neutrality in Buildings, DETAIL, ISBN-978-3-920034-80-5, Munich, 2011, http://shop.detail.de/eu_e/net-zero-energy-buildings.html

solar
decathlon
europe

# annex

Table A2.1: Overview of photovoltaic-specific requirements at all SD Competitions. A limitation of permitted installed power to a set maximum was first introduced at SDE10. Limits on PV system costs have applied for the SD since 2005. Source: University of Wuppertal; Susanne Hendel

| | US | | | | | | | | EU | | | | | CN | | LA | | ME | AF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PV rules | 2002 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2010 | 2012 | 2014 | 2019 | 2021 | 2013 | 2018 | 2015 | 2019 | 2018 | 2019 |
| PV power limitations per $kW_p$ | | | | | | | | 10 | 15 | 10 | 5 | 5 | 3 | | | | | 5 | 10 |
| PV cost limitations per raw cell | | \$5 | \$5 | \$5 | | | | | €6 | €6 | | | | | | | | | |
| PV cost limitations per cell | | \$10 | \$10 | \$10 | | | | | €12 | €12 | | | | | | | | | |

Table A2.2: Overview of battery-specific requirements at all SD Competitions. Batteries were allowed at all SDE Competitions. A limitation of permitted installed capacity was first introduced at SDE14. Source: University of Wuppertal; Susanne Hendel

| | US | | | | | | | | EU | | | | | CN | | LA | | ME | AF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Battery rules | 2002 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2010 | 2012 | 2014 | 2019 | 2021 | 2013 | 2018 | 2015 | 2019 | 2018 | 2019 |
| Batteries permitted | x | x | x | | | | | x | x | x | x | x | x | | x | | | | x |
| Batteries mandatory | x | x | x | | | | | | | | | | | | | | | | |
| Electrical grid connection | | | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Capacity limitations [kWh] | | | | | | | | | | | 6 | 6 | 2.5 | | | | | | 5 |

solar
decathlon
europe

Table A2.3: Overview of all energy-related disciplines and measurements. The table shows the more comprehensive assessment approach at SDE compared to international approaches. The measurements for energy balance and comfort in particular are more extensive. Source: University of Wuppertal, Susanne Hendel

| | US | | | | | | | | EU | | | | | CN | | LA | | ME | AF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Contest Criteria** | 2002 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2010 | 2012 | 2014 | 2019 | 2021 | 2013 | 2018 | 2015 | 2019 | 2018 | 2019 |
| **Comfort** | | | | | | | | | | | | | | | | | | | |
| Temperature | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Humidity | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Air quality | | | | | | | | x | x | x | x | x | x | | x | | | x | |
| Lighting | | x | x | x | | | x | x | x | | x | x | x | x | x | | | | |
| Airtightness | | | | | | | | x | | | x | x | x | | | x | x | | |
| Noise protection | | | | | | | | | x | x | x | x | x | | | | | | |
| Reverberation time | | | | | | | | | x | x | x | x | | | | x | x | x | |
| **House Functioning** | | | | | | | | | | | | | | | | | | | |
| Refrigeration | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Freezing | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Washing machine | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Clothes dryer | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| Dishwasher | | x | x | x | x | x | x | | x | x | x | x | x | x | x | x | x | x | x |
| Oven/cooking | | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | | x | x |
| TV/video operation/movie night | | x | x | x | x | x | x | x | | | | | | x | x | x | x | | x |
| Dinner party | | | | x | x | x | x | x | x | x | x | x | x | x | x | | | x | x |
| Computer operation/home electronics | | x | x | | x | x | x | x | | x | x | x | x | x | x | x | x | x | x |
| Blender | | | | | | | | | | | | | | | | x | x | | |
| Microwave | | | | | | | | | | | | | | | | x | x | | |
| **Water** | | | | | | | | | | | | | | | | | | | |
| Water consumption | | | | | | | | | | | x | x | x | | | x | x | x | |
| Hot water | | x | x | x | x | x | x | x | x | x | x | x | x | x | | x | x | x | x |
| **Energy Balance** | | | | | | | | | | | | | | | | | | | |
| Energy balance | | x | x | x | x | x | x | x | x | | x | x | x | x | x | x | x | | x |
| Temporary generation – consumption correlation | | | | | | | | | x | x | x | x | x | | | x | x | x | x |
| Electrical energy consumption | | | | | | | | | | x | x | x | x | | | | | x | |
| House adjustment to network load state | | | | | | | | | | | x | x | | | | x | x | | |
| Local self-sufficiency | | | | | | | | | x | | | | x | | | | | | |
| Electric autonomy | | | | | | | | | | x | | | x | | | | | | |
| Generating capacity | | | | | | | | | | | | | | | x | | | | |
| Maximum energy consumption | | | | | | | | | | | | | | | | x | x | | |
| Energy performance ratio | | | | | | | | | | | | | x | | | | | | x |
| **Mobility** | | | | | | | | | | | | | | | | | | | |
| Miles covered | | x | x | | | | | x | | | x | | | | | | | x | |
| Tasks done | | | | | | | | | | | | | x | | | | | | |

solar
decathlon
europe

Table A2.4: Overview of the data points and available measurement data from SDE Competitions in 2010, 2012 and 2014. Data from SDE19 are not made available by the organisers. Source: University of Wuppertal

| Measurements | | Entity | SDE 2010 | SDE 2012 | SDE 2014 |
|---|---|---|---|---|---|
| **Site** | | | | | |
| | Exterior temperature | °C | | | x |
| | Exterior humidity | °C | | | x |
| | Global radiation | W/m$^2$ | | | x |
| | Wind speed | km/h | | | |
| | Wind direction | ° | | | |
| **Energy** | | | | | |
| | Load power | W | x | x | x |
| | Appliances power | W | | | x |
| | Home electronics power | W | x | x | x |
| | Batteries power | W | | | x |
| | Energy generation | W | x | x | x |
| **Comfort conditions** | | | | | |
| | Temperature room 1 | °C | x | x | x |
| | Temperature room 2 | °C | x | x | x |
| | Temperature room 3 | °C | | | x |
| | Air quality | ppm | x | x | x |
| | Relative humidity | % | x | x | x |
| | Photometer | Lux | x | x | |
| **Appliances** | | | | | |
| | Fridge temperature | °C | x | x | x |
| | Freezer temperature | °C | x | x | x |
| | Washing machine temperature | °C | x | x | x |
| | Dishwasher temperature | °C | x | x | x |
| | Oven temperature | °C | x | x | x |

SDE _ THEMATIC REPORT _ 3/4 _

INCREASING IMPACT FOR THE SMART CITIES COMMUNITY

*EC TENDER #: ENER / C2 / 2016-502*

# solar decathlon europe

# 3. increasing impact for the smart cities community

*BEATRIZ ARRANZ, SERGIO VEGA SÁNCHEZ*

*UNIVERSIDAD POLITÉCNICA DE MADRID*

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar decathlon europe

# table of contents


| | | PG |
|---|---|---|
| | **Introduction** | **110** |
| **3.1** | **SDE Communication** | **113** |
| 3.1.1 | Activities and potential for children | 114 |
| 3.1.2 | Activities and potential for teenagers | 115 |
| 3.1.3 | Activities and potential for university students & the Scientific Community | 116 |
| 3.1.4 | Activities and potential for professionals | 118 |
| 3.1.5 | Activities and potential for the general public | 119 |
| **3.2** | **Fostering innovation: new technologies from sde to the market** | **121** |
| 3.2.1 | Innovation versus affordability | 122 |
| 3.2.2 | New technologies fostered by Competitions | 126 |
| 3.2.3 | New concepts fostered by Competitions | 132 |
| 3.2.4 | Successful showcases with influence in the market | 134 |
| 3.2.5 | Research, innovation and market opportunities | 141 |
| 3.2.6 | Policy makers | 142 |
| **3.3** | **Professionals & industry involvement** | **145** |
| 3.3.1 | Professional participation and awareness | 145 |
| 3.3.2 | Synergies from industrial participation | 146 |
| **3.4** | **Conclusions & lessons learned** | **147** |
| 3.4.1 | Smart cities potential | 147 |
| 3.4.2 | Fostering innovation and transferring it to the market | 152 |

solar
decathlon
europe

# introduction

**One of the greatest challenges facing the EU is to design and adapt cities into sustainable environments. Almost three quarters of Europeans live in cities, consuming 70% of the EU's energy (Eurostat and Directorate-General for Regional and Urban Policy -DG REGIO). This will be possible if a transition to smart sustainable cities is promoted. In 2012 the Commission launched the Smart Cities and Communities European Innovation Partnership (SCC EIP) to boost the development of smart technologies in cities.**

This chapter explores the value and impact that the SDE has and can have for the SCC EIP. The objective is to foster innovation and industry involvement, generate new ideas and disseminate the most efficient technical solutions. The effective implementation of sustainable smart cities needs the commitment of all stakeholders, from the supply side to the demand side, from policy to decision makers, from professionals to users and facility managers. All these stakeholders must be made aware. Industry and professionals may also benefit through channels that foster activities toward improved innovative technologies, energy efficiency, and sustainability.

This chapter will firstly delve into EIP-SCC and SDE synergies, secondly the SDE communication strategy and lessons learned will be described, sharing the SDE experience with the SCC EIP, awareness activities, communication, and innovative potential through actions with different target groups (professionals, industry, general public), all necessary for the active involvement of users in sustainable smart cities. Then, the potential uptake of innovative technologies from the SDE to the market is explored. The final section of the chapter explains how the involvement of professionals from the building sector strengthens this link to the market.

The European Innovation Partnership on Smart Cities and Communities (EIP-SCC) brings together cities, industries, SMEs, investors, researchers and other smart city participants, and is a major market-changing undertaking supported by the European Commission.

The EIP-SCC Marketplace offers an on-line Market Place which plays a distinctive and new role engaging cities, industry and financiers in interest matching activities, leading to project design, with delivery being the Marketplace's team objective.

An Action Cluster is an assembly of partners committing to work on specific issues related to smart cities, by sharing the knowledge and expertise with their peers, giving added value to their national and local experience and identifying gaps that need to be filled at European level. The work of each Action Clusters is gathered under thematic Initiatives. Six Action Clusters organize a Marketplace of 6 000+ partners from over 31 countries. The Solar Decathlon Europe has generated knowledge and expertise in all these six Clusters:

solar decathlon europe

i **SUSTAINABLE DISTRICTS & BUILT ENVIRONMENT**

From the first Solar Decathlon Europe Competitions passive strategies and high-energy-efficient solutions as the way to reduce building energy consumption and increase energy efficiency were fostered. At the first Solar Decathlon Europe event, the performance of the houses was continuously monitored while they were being evaluated for the ten contests of the Competition. Passive strategies and the use of high-efficiency solutions in the houses played a decisive role in the Competition since they had to operate with minimum energy consumption in order to be successful. The 68 buildings produced until now through the Solar Decathlon Europe, with their harmonize passive/active architecture/construction/HVAC/RES/smart-grid integrated energy efficiency, have opened up a new frontier for sustainable energy in buildings and settlements of the future.

ii **INTEGRATED INFRASTRUCTURES & PROCESSES**

The electricity at the 'Villa Solar' was managed by the SDE Smart Grid; all the buildings, including the participating houses, were connected to it. Since the participating houses were connected to the energy grid and were designed to produce more energy than they consume, they were recognized as Net Zero Energy Buildings (Net ZEB) and Net Zero Energy Cluster (Net ZEC). In the first Competition in 2010, the first microgrid in Spain was designed and implemented, and was used to support the Competition. In the 2012 Competition, there were additional challenges. An intelligent distribution network was created operating in a way that was both comprehensible and visible: the visitors to the Solar Decathlon Europe had to understand how energy is managed in a smart environment. The electric systems in the houses were connected to an internal (partially smart) micro-grid, that interconnected the houses and their solar panels, linking them directly to the Grid through two MV/LV (medium voltage/ low voltage) substations and thereby helping to create a net-zero energy home, and a Net Zero Energy Cluster, balancing the energy flows, adapting the energy supply to the demand in real time, and injecting the surplus energy into the Grid. This is a very important aspect of the SDE Competitions, as modern society is becoming increasingly dependent on electricity.

iii **SUSTAINABLE URBAN MOBILITY**

The Solar Decathlon Europe Solar Village in 2010, 2012 and 2014 integrated Solar Houses, Organisation buildings and electric cars. The surplus energy obtained from the houses was used for Solar Village events and for transportation. In 2014 the 'Urban Design, Transportation & Affordability'. Contest was included in the Competition and in SDE19 the 'Neighbourhood Integration and Impact' Contest which considers the urban mobility was instigated. SDE21 considers 'urban mobility' as a discipline.

iv **BUSINESS MODELS, FINANCE & PROCUREMENT**

The European SD Organisation considered some changes in the Rules and regulations of SDE to favour the industrialization and market viability of the prototypes in 2010. The industrialization of construction would guarantee a higher level of control of the process, which will lead to higher quality, controlled costs and controlled time. In SDE12 the positive assessment of the affordability concept in the section on market viability and the multifamily houses in the industrialization contest was integrated. Industries are aware of the Solar Decathlon Europe potential; they are involved in sponsoring University Teams and testing building innovative products.

solar
decathlon
europe

## v CITIZEN FOCUS

In contemporary societies, the protection of the environment has become a value, a positive and desirable reference. The population perceives the deterioration of the environment as a serious and worrying problem. There are two items related to citizens that are approach in Solar Decathlon Europe. In first place, the user behavior, aware citizens will make a responsible use of the resources and in second place, the innovative building design must consider the final user needs, designs must be 'user friendly' to be successful. Regarding citizens awareness Solar Decathlon Europe communication strategy was strengthened in Solar Decathlon Europe 2010 (partially) and Solar Decathlon Europe 2012 by the 10Action Project. This project looked for ways to encourage behavioural changes in European citizens. It has successfully carried out 73 different activities, and it has reached 174 861 European citizens who have learned and thought about energy and sustainable issues, with specific activities for them, and more than four million European citizens have received news about the values promoted by the SDE. For example, 220 000 people visited Solar Decathlon Europe 2012, where activities, as well as debates, conferences took place. The process of designing sustainable dwellings is essentially iterative and progressive; this requires close collaboration between architects, building services and construction engineers, and ideally should consider the views of end users. Solar Decathlon Teams approach the role of the user in their proposals. Multiple solutions are exploring, from high technological active solutions connected with the user through 'friendly' apps to low energy houses where the active involvement of the user is essential.

## vi INTERGRATED PLANNING, POLICY & REGULATIONS

Institutional leadership was crucial for SDE to fulfil its objectives and included the Spanish Government (Ministry of Public Works and the former Ministry of Housing), IDAE (Institute for Diversification and Energy Saving), the energy agency of Spain and the Department of Energy of the United States. Special events for policy-maker awareness took place, and there were visits from mayors, the President of the Regional Government of Madrid, the Spanish Prime Minister, the President of Hungary, Ministers from Spain, France and Hungary and the King of Spain (in the SDE10, he was the 'Prince of Spain' before becoming the King). In the SDE10 all the Housing Ministers of the European Union visited the Solar Village, with the great potential for influencing all those responsible for building and cities in the different countries of the European Union. Solar Decathlon Europe Rules are aligned with European Directives. Consequently, they encourage the reduction in energy consumption, the increase of building energy efficiency, and the use of renewable energies, preferably produced on site. The Solar Decathlon Europe demonstrates that technology is ready to achieve the decarbonisation of the building energy needs and the organisers are aware of the importance of engaging the political process that makes and transforms cities. The SDE has been aligned with The Sustainable Development Goals (SDGs) since 2015, when UN countries adopted the 2030 Agenda, specifically, with SDG 17 'Partnership for the Goals'.[1]

[1] SDG 17 "Partnership for the Goals": A successful sustainable development agenda requires partnerships between governments, the private sector and civil society. These inclusive partnerships built upon principles and values, a shared vision, and shared goals that place people and the planet at the centre, are needed at the global, regional, national and local level.

## 3.1 sde communication

The SDE Competitions have proven to be a very powerful vehicle for demonstrating and communicating the potential and benefits of energy-efficient construction to a wide public, ranging from building professionals to academics and the general public. In the SDE10 (partially) and the SDE12 the communication strategy was strengthened by the 10Action Project. A supplementary extension of the communication activities developed in Solar Decathlon Europe 2012 was funded by Intelligent Energy Europe. This initiative also included the active support of more than twelve additional European countries that collaborated to organize specific activities. This project looked for ways to encourage behavioural changes in European citizens, promoting education, social awareness and the dissemination of the responsible use of energy, increasing energy efficiency, developing renewable energy integration, and improving the conditions of sustainability in our buildings and cities.



Figure 3.1: EU Prize of Sustainable Energy Award Solar Decathlon Europe-Team and members of the Spanish Ministry.

The synergy reached between the Solar Decathlon Europe and 10Action project, and the shared strategy with participant Teams and sponsors generated more than a hundred activities for children, adolescents, university students, professionals and the general public, which fulfilled the proposed objectives of these initiatives. The overall balance only for the SDE10 and 2012+10Action in terms of communication is overwhelming: Public & private institutions taking part from 34 collaborating countries, 48 universities participating out of university applicants (among 800 universities contacted), 400 researchers and PhD Students collaborating with the Teams, 3 500 volunteers, more than 25 000 children and teenagers taking part in activities, 7 000 university students taking part in workshops and courses, 25 000 professionals from twelve EU member countries, significant scientific output (books, papers, journals, patents, PhD theses), over 680 000 people participating, over 700 000 000 individuals reached through activities and media. Because of this, the Solar Decathlon Europe has won many awards throughout these years, with the especially important EU Prize for Sustainable Energy Award in Communication during the Sustainable Energy Week 2011, and the Energy Endeavour Foundation was awarded with the European Solar Prize 2018 in the category One World Cooperation, into Eurosolar.[2]

[2] https://www.eurosolar.de/en/index.php/text-and-media/press-releases-eurosolar/850-renewable-energies-european-solar-prize-2018-awarded-to-eight-winners

solar
decathlon
europe

The global approach to the communication plan, the strategy to increase awareness for every target group, and many different activities developed for them could be useful and interesting for future initiatives from the Smart Cities Community. One of the key drivers for a successful awareness event like the Solar Decathlon Europe Competitions is to benefit from all opportunities that arise, with clear objectives and strategies to reach every target group. The 10Action project was developed by seven partners working together towards raising awareness of energy issues, trying to influence peoples' attitudes, obtaining a reduction in energy consumption. Five target groups in twelve different countries have been addressed. All partners were involved in almost all the activities, a strong interaction between partners was needed. The experience of organising the activity in one country was transferred to other partners, the particularities of each gave rise to problems which needed to be solved. Materials were developed by the leaders and later were translated and adapted to be used in other countries.

The overall communication strategy comprised two general dimensions: Although the core of the communication plan was to transmit the message, the creative expression was the key to making it appealing to every target group. The Internet was the key strategy chosen and other conventional media channels were considered: promotional events, press, radio, etc.

### 3.1.1 Activities and potential for children

Children represent the future of Europe; the objective of the programme was to provide educational material to teachers so they can give the children adapted information and to develop games to make them aware of the small gestures in their day-to-day habits to save energy and reduce $CO_2$ emissions. Many different activities were carried out such as 'How to Save Energy in Our Life Game'; Workshop - Reduce $CO_2$ Production Webgame + Energy Worksheets; International children drawing competition.

Figure 3.2: Pictures from 10Action "Drawing Contest".

In Austria 31 handicraft workshops were organised in schools interested in co-operation with the Austrian Climate Protection Alliance. For instance, more than 3 000 children participated in workshops organised during Solar Decathlon Europe 2012. A Webgame called 'My Energy Smart Home' was produced in English, German, Greek, Spanish and Portuguese. The webgame was used on the Internet more than 8 000 times, and as complement to other activities in many events. In ten easy understandable steps children can build and furnish their homes and assess the eco-friendliness of their houses. As meaningful complement fifteen graphically appealing work sheets have been produced, which teachers can use to supplement their lessons.

solar
decathlon
europe

Figure 3.3: "Create your own Solar Village" Workshop results with children.

An international child drawing competition was launched in the SDE12 with the best drawings being exhibited. This has been successful because the activities have been developed using already existing institutional settings and communication channels such as eco-schools to create synergy effects and to avoid costly efforts with no adequate results. An analysis of the special needs of the target group was made before starting to design the activities. Activities for children need special communication channels such as children's magazines and especially a language suitable for them to understand. The activities were designed to be fruitful for children with learning disabilities and not just for highly skilled. It was very important that from the beginning two organisations were involved: one experienced in working with children and another one specialized in energy issues. It was important to look for alliances, when addressing children and teachers, because not in every country the direct access to schools was possible. It was not important to have a huge marketing budget, but it is important to select the appropriate communication channels. They are very specific ones for teachers and children.

### 3.1.2 Activities and potential for teenagers

As regards adolescents, the objective of the program was to contribute to raising awareness through personal motivation and involvement. 1 550 000 Teenagers were reached through the communication program. It was based on providing educational material, directing teachers and providing adapted information, so adolescents get involved in games and debates to consolidate their civic conscience, favouring more sustainable habits and models to share with their families.

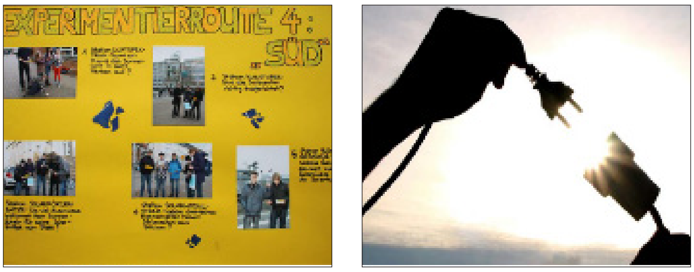
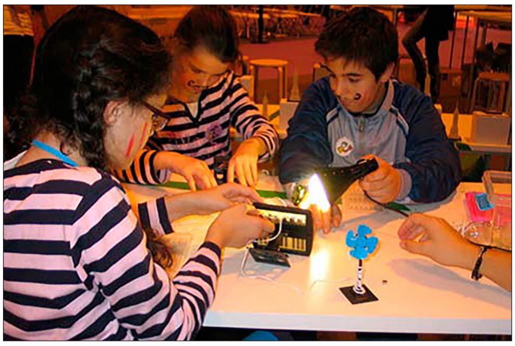



Figure 3.4: 1st Prices, Solar Design Competition "Ideas for the future" and Photo Competition "Energy in Focus" (children and teenager's activities)

Many different activities were carried out for teenagers such as a debate 'How we want our own solar village', a Solar Design Competition 'Ideas for the future' and a Solar Photo Competition 'Energy in Focus'. Through a planning game, students can put themselves into the positions of different participants in urban planning. In addition to the debates, a series of lessons and educational material were developed to help the teacher. The material for the debate 'Energy + Architecture' was developed in English, Spanish, Greek and German. The activities of the Solar Design Competition were implemented in Greece, Austria and Germany reaching 752 adolescents (194 devices). Competition leaflets, posters and Rules were prepared in English, Spanish, Greek and German. Participating students were asked to develop ideas for 'The Town of the Future' (age group 10-14 years) or 'The Building of the Future' (15-19 years).

Problems and challenges were to be discovered and explored. The activities of the Solar Photo Competition were implemented in Greece, Portugal, Spain, Austria and Germany reaching 1 303 adolescents (1 582 photos). The playful introduction to the subject of renewable energy through the creative medium of photography gave rise to the direct examination and reflection of participants' own behaviour.

Figure 3.5: On the left, Ciclab Solar; on the right, Science workshop.



Thus, the student competition was aimed at awakening interest in energy and sustainability and the consciousness of one's personal contribution starting at an early age; one small step on the way to achieving long term behavioural changes as regards the use of energy and the source of $CO_2$ emissions. Motivation of teachers makes a difference for teenagers. Most of the teachers are extremely busy, struggling to implement their normal, required curriculum and feel unable to acquire additional new knowledge. The collaboration with the Ministries of Education is necessary to get the topics of renewable energies and finite resources included in the required school curriculum. A lot of time and effort was necessary to achieve collaboration with the Ministries of Education, especially in countries where education is subject of individual federal states. Unfortunately, most of them were reluctant to transfer information to their school contacts. In some countries, a lot of well-respected competitions already exist (Jugend Forscht, NaturPur Award, etc.), which are primarily on the teachers´ radar and field of interest. The assistance of experts from the field of media management and communication is necessary to make the competitions more attractive for the teenagers. A lot of effort was necessary to implement the competitions internationally. Synergy effects from the joint preparation of materials such as leaflets and competition Rules helped to accelerate the implementation of the competitions.

### 3.1.3 Activities and potential for university students & the Scientific Community

Reaching this target group has doubled their interest: first, seeking to consolidate the generation of awareness and training, and second, accessing the most effective knowledge creator and knowledge disseminator in Europe: The Universities. These activities aimed at encouraging the commitment and imagination of university students, not only Decathletes but students from other European universities, to contribute to modifying habits with ideas in order to reduce $CO_2$ emissions, improve energy efficiency in buildings and bring about a more sustainable world.

solar
decathlon
europe

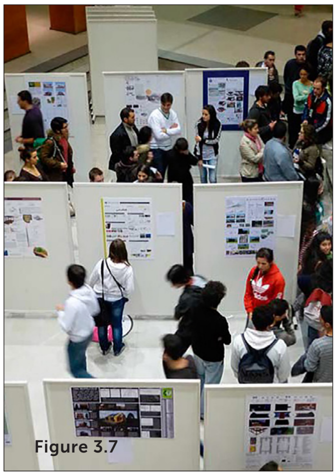




Figure 3.6: SDE12. Image of "Solar Village" (Villa Solar).

Figure 3.7: Exhibition, MORE with LESS [emissions].

The active participation of the Scientific and University Community ensured the dissemination of knowledge and helped to generate the new concepts necessary to achieve the European objectives. Many different activities were carried out such as the 'MORE about LESS [emissions]' debate, Ideas Competition 'MORE with LESS [emissions]', Technical Workshops, etc.
The debates on how we want our own Solar Village 'MORE about LESS [emissions]' were implemented in Madrid (2012) as well as by the Moodle online system reaching 1 180 students. These participants of the fifteen debates organised during the SDE12 and the online system came from 46 different universities or schools and fifteen countries: Spain, Germany, UK, Finland, Greece, France, Austria, Romania, Egypt, Brazil, China, Japan, Bulgaria, Portugal and Italy.
The aim of the debates was to provide the students with knowledge to be able to think for themselves on how an ideal city should be from an energy point of view, without forgetting the basics of urban development. In addition to the debates a series of lectures were developed in pdf and PowerPoint format, in English and Spanish, related to the main topics to be considered throughout the debates: consumption and production of energy, bioclimatic urban planning, materials and constructive systems, sustainable industrialization and environmental control both passive and active systems. Ideas Competition on impossible ideas for a possible world 'MORE with LESS [emissions]'. The competition received 43 submittals and 221 participants from 30 different universities and schools. The main aim of the competition is to obtain new conceptual ideas on how to deal with the energy issues that are affecting our world, both in construction and urbanization schemes.

Numerous Technical Workshops were carried out in Portugal, Spain, Germany, France, Spain, Finland, Greece, England and Austria with 747 participants from 25 universities. The goal of the technical workshops is to raise awareness about the responsible use of energy and energy efficiency in buildings among graduate and undergraduate university students. Organised with the help of different universities, the workshops were oriented towards awareness, with objective data, of the use we make of natural resources and the low energy efficiency of many everyday processes, followed by showing the technologies available on the market for the use of renewable energy and improve the efficiency of our activities and everyday activities.

solar
decathlon
europe

Thousands of university students and professors visited the solar houses in every edition of the Competition, both, during the assembly and disassembley processes, and during the Competitions. Later, back in their universities the reassembled solar houses have been used as living labs, demonstrators, and research facilities, reaching again thousands of university students and professors for education and research.

58 Universities from around the world have participated in the four Solar Decathlon Europe Competitions held to date. Over 400 researchers and PhD students have participated in research projects, directly or indirectly associated with the SDE. It was hard to reach the target group through the universities. We learned that the best way to reach the students was through their professors. When we came across a motivated and interested professor, we had access to his or her students, and would take care of implementing our activities. One of the most successful activities was the organisation of workshops because it was where we could really confirm the gain in knowledge on behalf of the students. To have a bigger outcome of these results it could be very interesting to video record all workshops in order to make them accessible to all students or to use online streaming.

The Solar Decathlon Europe continues to provide opportunities for the education of university students and the scientific community. It is worth mentioning the workshops and tasks developed within the scope of Annex 74 of the EBC program (Energy Buildings and Communities) of the International Energy Agency, (on Monitoring, or the Figure 3.7. Exhibition, MORE with LESS [emissions] development of topical papers on various topics of scientific interest such as energy balance, batteries, solar energy, comfort, heat pumps, air tightness, ventilation, simulations,... ), or the activities developed during the SDE19 Competition held in Szentendre (Hungary), or those that are being prepared for the next SDE21 Competition to be held in the city of Wuppertal (Germany) (https://sde21.eu/downloads)

### 3.1.4 Activities and potential for professionals

Professionals from the building sector must be involved in the achievement of European Union objectives. The objective was based on providing all the available information and transfer of innovative technology to the market, using existing mature technology to build 'zero emission' buildings, looking to generate change in the technical and productive model. Many different activities were carried out as an active participation in the most important International European Trade Fairs - Organisation of International and National conferences, Workshops. The total attendance to these fairs was of 486 885 people in 2011 and 2012.

In order to reach the biggest target audience possible and to pass our messages on to key market players and professionals, workshops and conferences were organised[3] within the International Trade Fairs exhibitions framework in some of which scale models participating in the SDE10 and SDE12 Competitions were shown. Conferences were organised within the most important energy, architecture and environment international trade fairs in Europe. To have a big audience means that a huge dissemination effort is needed before any promotional activity.

[3] BAU Trade Fair (Munich 2011). Urba Verde Fair on Sustainable Cities (Estoril 2011). Workshop on "Eco-Urbanism and Eco-Architecture". GENERA'11, International Energy & Environment Trade Fair (Madrid 2011). Construmat'11, International Construction Exhibition & Trade Fair, (Barcelona 2011) Conference on "Nearly zero-energy buildings, from research to real construction". DEUBAU Trade Fair, (Essen 2012), Conference on Aesthetics of Sustainability in architecture and communication. GENERA'12, International Energy & Environment Trade Fair, (Madrid 2012), Conference-Debate on "Nearly zero-energy buildings: new construction and refurbishment". Workshop on the "URSOS Programme: Software for the development of sustainable urbanism", Madrid at Solar Decathlon Europe 2012 Exhibition.

Figure 3.8: Conference-Debate on "Nearly zero-energy buildings", GENERA 2012, Madrid, Spain.

It must be borne in mind that to get a successful response from dissemination campaigns is to obtain 2% to 5% of positive answers or participation. For this reason, we have made direct e-mail shots to more than 22 000 people on two occasions. This was a key point for gathering the audience we have got in our conferences/workshops. It was important to use innovative formats for the conferences and new means of communication. Professionals are already bored with conventional presentations, therefore to organize a debate, such as the one held in GENERA 2012 on 'Nearly zero-energy buildings' was very successful, but even better was to broadcast the event online, which had guaranteed a very high participation as well as the involvement of all the Conference speakers. All participant Professional Associations were very active before and after the event, they have placed publicity and articles in their web pages. To broadcast the conference - debate had increased the interest and involvement of the professional associations at the conference. The professional associations saw this event as an opportunity to advertise themselves among their clients and within the GENERA trade fair.

Many other activities have subsequently been organised for professionals from all over the world who are linked to the Solar Decathlon Europe Competitions, their houses, and their technologies. To mention some relevant ones, for example, the participation in the World Future Energy Summit 2013 Abu Dhabi (United Arab Emirates), the workshop on the professional potential of SDE in the World Sustainable Building 2014 Conference, organised by the Green Building Council held in Barcelona 2014, or the special SDE workshop at Bau2015 in Munich, held by the German Federal Ministry of Economic Affairs and Energy.

### 3.1.5 Activities and potential for the general public

The general public was identified as the most efficient, in the short term, in raising awareness onhow small behavioural changes may save a great amount of annual emissions of $CO_2$, ensuring a more sustainable world. The objective was based on maximizing the media impact and dissemination to enhance European Union objectives, especially those related to energy savings. Many different activities were carried out by European SDE universities to develop activities and exhibitions in their houses both before and after Competition, as well as the organisation of SDE House exhibitions. The organisation of SDE scale model exhibitions, and the Competitions themselves were key drivers, with dozens of activities and exhibitions aimed at the social awareness of visitors in every edition of the Solar Decathlon Europe.

Figure 3.9: Scale models of the SDE house prototypes exhibition.

Figure 3.10: Public visits to CANOPEA House. SDE12.

Figure 3.6

Figure 3.6

The scale models of the SDE house prototypes have been used for travelling exhibitions so that the general public could visit the scale models of the SDE10, SDE12, and SDE14. Along with the scale models, audio-visuals were integrated into the exhibitions, explaining the different technologies to the public and showing the importance of making a responsible and effective use of energy. There were many scale model exhibitions implemented in energy fairs in Spain, Germany and Portugal, making a great impact. Furthermore, there has been a connection with other activities and fairs aimed at children (mainly in the exhibitions that took place in Madrid). The main idea of the house exhibitions during the SDE editions, was to provide comprehensive guided tours for the general public. This activity would familiarize the general public to new energy-efficient technologies. Thousands of people visited every single house during the house exhibitions. They enjoyed the houses and had the opportunity to listen to the enthusiastic explanations of the students about the active and passive strategies they had implemented to make their homes more sustainable.

The feedback received from the visitors to the solar houses, both at every Competition, and at their own university location, was excellent. According to a 10Action Survey, 81% of the visitors believed that the exhibition of energy-efficient houses was meaningful since it provided useful information on innovative technologies to the general public. Another interesting fact is that the 70% of the visitors would be interested in buying the exhibited house they visited.


Figure 3.11: SDE model exhibition in Madrid Science Week.

Some of the houses have been exhibited at their corresponding university campus after the Competition, or in the case of the Rosenheim University of Applied Sciences, Aalto University and Universidad de Sevilla, at a trade fair. They have received a total number of 94 000 visitors. The scale model exhibition of the Solar houses of the SDE10 and SDE12 (Figure 3.11) were displayed at nine different trade fairs with a total amount of 51 252 visitors. The exhibitions of energy-efficient houses are an impressive way of informing the general public about new innovative technologies in a practical manner. From the feedback received, the exhibitions proved to be a significant tool for raising the energy awareness of European society. The collaboration between the universities and local schools in order to establish continuous school visits to the exhibitions works positively for the schoolchildren. It is an interesting environmental tour that improves the students' knowledge of energy issues. This is clear from the feedback received at exhibitions where most visitors were children and young people. Universities were more focused on the research concept (taking measurements in their houses, etc.) than informing the public on new innovative and energy-saving technologies. Since most of the universities rebuild their houses after the SDE Competitions, it is important to utilize the houses as much as possible, not only for research purposes but also for guided tours in order to raise the energy awareness of the European citizens. The visitors can see with their own eyes the technologies that are integrated into the house and receive crucial information from the scientific staff of the Universities. In the SDE19, in Hungary, for the first time it has been possible for the wider public to visit the prototypes together in one place in the form of a two-month extended exhibition.

solar
decathlon
europe

## 3.2 fostering innovation: new technologies from sde to the market

Solar Decathlon Europe Competitions have pursued essentially similar objectives from the first edition (SDUS02), but the introduction of wider and more up-to-date ambitions since then has had an impact on the Competition results. The achievement of these objectives has led to some changes in the Competition's contests, however following the structure of the Olympic decathlon, the Solar Decathlon Competition is conceived to have ten different contests. These contests are designed to gauge how well the houses perform, how liveable and how sustainable they are. When the Government of Spain, through the Ministry of Housing, asked the Universidad Politécnica de Madrid to organize the 2010 and 2012 Solar Decathlon Europe Competitions, they specified two main objectives[4]:

[4] "Solar Decathlon 2010. Towards Energy Efficient Buildings".

1. **Promoting innovation and generating knowledge** to improve the performance of energy-efficient buildings, integrate renewable energies, and help to achieve conditions of sustainability in buildings and cities.
2. **Transferring this knowledge** to industry and professionals, in order to create a core group of technicians who could integrate innovative, eco-energetic solutions into their routine designs and activities.

SDE considered some mayor changes in the Rules and regulations to favor the attainment of the objective of promoting innovation. Table 3.1 gathers contests and scoring of both SDUS and SDE. The categories which were clearly defined in the objectives of the SDE10 Competition were: architecture; engineering and construction; solar systems; electrical energy balance; comfort conditions; appliances and their functionality; communication and social awareness; industrialization and market viability; innovation; and sustainability, the last four being new and very different from the categories included in the previous US versions of the Competition. The contests for the SDE12 Competition were Architecture, Engineering and Construction; Energy Efficiency; Electrical Energy Balance; Comfort Conditions; House Functionality; Communication and Social Awareness; Industrialization and Market Feasibility; Innovation; and Sustainability. Among many other changes, it is worth mentioning the introduction of the positive assessment of the affordability concept in the section on market viability and the multi-family houses in the industrialization contest.

**Table 3.1: Solar Decathlon Contests evolution from SDUS09 to SDE10**

Contests US SOLAR DECATHLON

| Contest | Points | Group total |
|---|---|---|
| Architecture | 100 | 200 |
| Engineering | 100 | |
| Net Metering | 100 | 100 |
| Comfort Zone | 100 | 500 |
| Lighting Design | 100 | |
| Hot Water | 100 | |
| Appliances | 100 | |
| Home Entertainment | 100 | |
| Communications | 100 | 200 |
| Market Viability | 100 | |

Contests SOLAR DECATHLON EUROPE

| Group | Contest | Points | Group total |
|---|---|---|---|
| Architecture | Architecture | 120 | 200 |
| | Engineering & Construction | 80 | |
| Energy | Energy Efficiency | 100 | 220 |
| | Electrical Energy Balance | 120 | |
| Comfort | Comfort Conditions | 120 | 240 |
| | House Functioning | 120 | |
| Social Economic | Communication & Social Awareness | 80 | 160 |
| | Industrialization & Market Viability | 80 | |
| Strategic | Innovation | 80 | 180 |
| | Sustainability | 100 | |

solar decathlon europe

In the SDE14, which was held in Versailles, the goal of the Competition was to contribute to the knowledge and dissemination of industrialized, solar and sustainable housing. It is intended to provide habitats that meet the triple challenge of energy, environment and society that we are all facing.[5] Similar objectives were pursued at the SDE19 held in Szentendre, Hungary: 'to contribute to the knowledge and dissemination of industrialized, solar and sustainable housing.' a subtle nuance: *"it is intended for habitats that meet the triple challenge that our societies are all facing: energy, environment and equitable living."*[6]

[5] Solar Decathlon Europe 2014 Rules and Regulation Document.

[6] Solar Decathlon Europe 2019 Rules and Regulation Document.

**Table 3.2: Solar Decathlon Europe Contests evolution from SDE10 to SDE19**

| | Architecture | Engineering | | Communication and Social Awareness | Comfort Conditions | House Functioning | Electrical Energy Balance | Innovation | Sustainability | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2010** | 120 | 80 | Industrialization and Market Viability 80 | 80 | 120 | 120 | 120 | 80 | 120 | Solar systems and Hot water 80 | |
| **2012** | 120 | 80 | Industrialization and Market Viability 80 | 80 | 120 | 120 | 100 | 80 | 100 | | Energy Efficiency 100 |
| **2014** | 120 | 80 | Urban design, transportation and affordability 120 | 80 | 120 | 120 | 120 | 80 | 80 | | Energy Efficiency 80 |
| **2019** | 100 | Engineering and construction 100 | Neighbourhood Integration & Impact 100 | 100 | 100 | 100 | 100 | Innovation and viability 100 | 100 | | Energy Efficiency 100 |

Since 2010 the Solar Decathlon Europe has been in continuous improvement, changes in the SDE contests since then can be seen in Table 3.2. 'Urban design and transportation' was a contest for the first time at the SDE14, and likewise the 'Neighbourhood integration and impact' contest, debuted at the SDE19. All the houses of the Solar Decathlon Europe have some degree of innovation. This innovation can be attained in many ways: it can be implicit in the philosophy of the project, for example by posing an absolutely conceptual analysis, questioning our lifestyle. In other cases, innovation can be embodied in the architectural or urban approach, or in others it can be about technological innovation. Innovation does not have a specific form. As a result, the Solar Decathlon Europe has a wide range of innovative aspects, whose transfer to the market is not always immediate or evident. We must necessarily refer to the Thematic Reports of Building Design & Construction, and Energy Engineering where the technologies used by the Teams in the editions of the Solar Decathlon Europe held so far are analyzed in detail.

In this section, an analysis of this innovation is carried out, organised in four subsections, with the intention of addressing the analysis of the impact that Solar Decathlon Europe had on the market. The first subsection deals with 'innovation versus affordability', revealing the link between cost and innovation, a controversial topic present at the different editions of the SDE. Secondly, a look at the innovative technologies and concepts fostered by the SDE is presented, without the intention of listing a catalogue of all the technologies present at all the editions but to transmit the implicit creativity contained in the proposals. Thirdly, cases with a clear influence in the market are gathered and finally, the involvement of policy makers is set out.

### 3.2.1 Innovation versus affordability

Innovation and affordability are two concepts evaluated at the Solar Decathlon Europe with a greater or lesser importance in the different Competitions. Table 3 details the points obtained at each Competition regarding innovation or affordability (market viability, viability, market).

solar
decathlon
europe

As seen in Table 3.3, the evaluation of these areas has changed from one edition to another both in the US and in Europe. In the SDE10 for the first time 80 point were specifically attributed to promoting innovation, without ignoring industrialization and market viability. In previous editions, innovation did not have specific points. In the European editions that fo lowed, the promotion of innovation has been maintained and it is remarkable to observe its influence on the design of the houses and the technologies incorporated in each edition.

Table 3.3: Scoring regarding contest related to innovation, affordability & market in US an EU Editions.

| | SD US 07 | SD US 09 | SDE 10 | SD US 11 | SDE 12 | SD US 13 | SDE 14 | SD US 15 | SD US 17 | SDE 19 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Market Viability** | 150 | 100 | | | | | | | | |
| **Industrialization and Market Viability** | | | 80 | | 80 | | | | | |
| **Innovation** | | | 80 | | 80 | | 80 | | 100 | |
| **Affordability** | | | | 100 | | 100 | | 100 | | |
| **Market Appeal Contest** | | | | 100 | | 100 | | 100 | | |
| **Urban Design, Transportation & Affordability** | | | | | | | 100 | | | |
| **Market Potential** | | | | | | | | | 100 | |
| **Neoghbourhood integration & impact** | | | | | | | | | | 100 |
| **Innovatopn & Viability** | | | | | | | | | | 100 |

The evolution of the housing concepts demonstrated over the years in the Solar Decathlon Europe is not by chance. Behind the changes proposed by the organisers there is a philosophy. The intention is to foster the focus on the students' creativity, interest and effort towards the materialization of new ideas and the resolution of current issues, aligned with European needs and policies. Students are required to consider the reality of taking their designs to market at this early prototype stage, but innovation is also a key focus of the Competition.

The most substantial changes in the SDE10 Competition were the evaluation of Innovation, Sustainability, Industrialization and Awareness. In the SDE12, energy efficiency performance, affordability and multifamily houses were profiled. In the SDE14, Urban design and transportation was introduced. In the SDE19, it was Neighbourhood Integration and Impact. Since SDE10, Innovation and Sustainability contests have been interwoven and evaluated with the other eight contests (Figure 3.12).

solar
decathlon
europe

Figure 3.12: Scoring regarding Innovation and sustainability SDE.

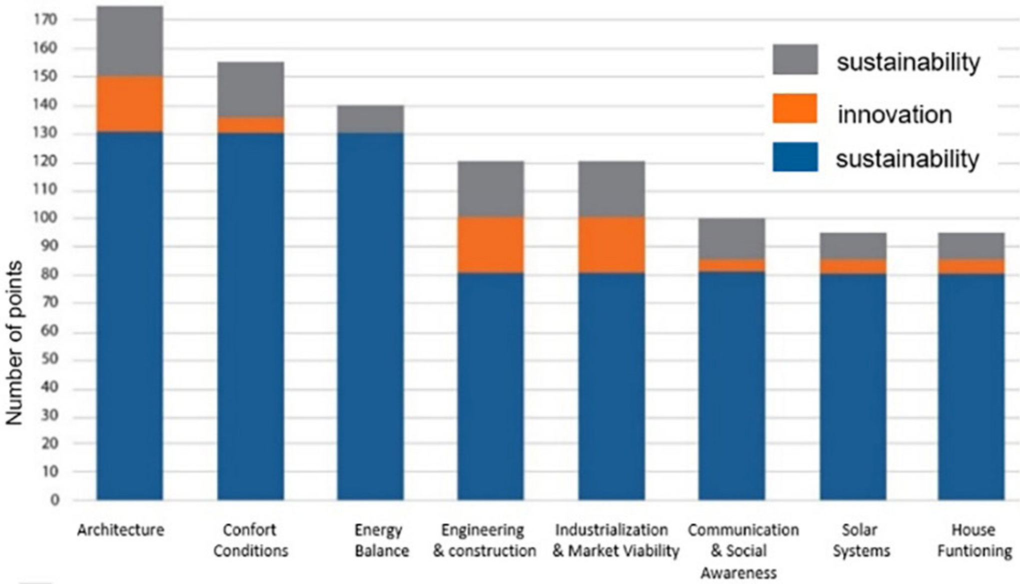



Figure 3.13: Prispa House. SDE12 explores low-budged alternative solutions.

Figure 3.14: Conopea House. SDE10. Individual homes stacked up to form a small tower.

Figure 3.15: Rooftop House. SDE14. Exploring rooftops.

The students' attention was drawn not only to designing and building houses, but also to integrating innovation and sustainability into each of their decisions during the design and building processes. A positive integration of innovative technology was seen in the SDE10 compared to previous editions in which innovation was not a contest. The organisation approach led to a more innovative house design, innovative construction solution, innovative sustainability approach, and overall innovative technologies. In the SDE12 energy efficiency performance, affordability and multifamily houses were considered.


Figure 3.13


Figure 3.14

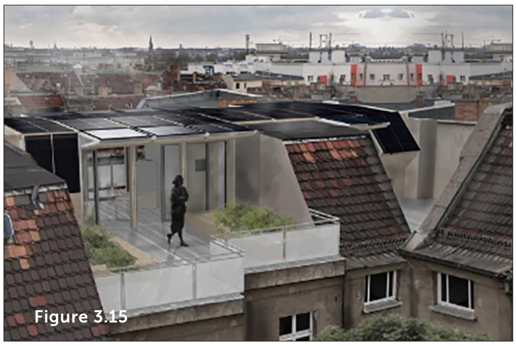


Figure 3.15

In the SDE12 edition, a wider range of possibilities for sustainable building practices and solar energy were proposed. From modest proposals in which a single dwelling in a rural environment is given the task of teaching an entire country about sustainability (Figure 3.13) to highly sophisticated proposals for dense urban conditions (Figure 3.14).

solar
decathlon
europe


Figure 3.16


Figure 3.17

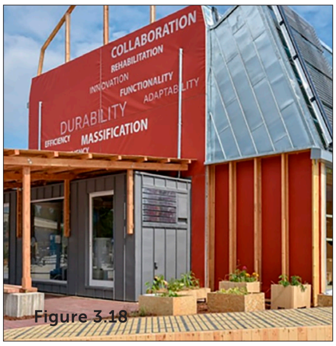


Figure 3.18

**Figure 3.16: Tropika House. SDE14. Explores sustainable housing for older people.**

**Figure 3.17: Project Aura 3.1. SDE19 explores interdisciplinary and sustainability.**

**Figure 3.18: Project Habiter2030 (H2030) explores sharing and exchange strategies.**

In the Solar Decathlon Europe 2014 at which 'Urban design and transportation' was included, the house designs brought more conceptual complexity, trying to solve problems was considered for the first time in the Solar Decathlon Europe. Some new approaches in SDE14 were: home co-sharing, buildings on top of existing buildings to be retrofitted (Figure 3.15), plug-in cities, the refurbishment of terraced houses, proposals facing major natural threats (floods, typhoons, earthquakes), proposals for facing social contemporary problems (demographic expansion & urban high density, aging population (Figure 3.16), sustainable mobility, etc.). In the Solar Decathlon Europe 2019, including the contest 'Neighbourhood integration and impact', led to some interesting approaches considering the retrofitting and renovation of suburban areas, rural settlements and vulnerable regions, not only adapting existing buildings to current requirements but adding value to the existing built environments and territories. Most of the proposals focus on the existing architectural context, emphasizing the value of the existing structures, preserving and upgrading them and considering the impact on their inhabitants. In the SDE19 edition of the Solar Decathlon, innovation focused on social challenges. *"This is not a house"* was the Project Aura 3.1 slogan (Figure 3.17), *"This is a strategy based on urban, social and environmental regeneration."*
Through this proposal the Team demonstrated its inquisitiveness for interdisciplinary and sustainability. In the Habiter2030 project (Figure 3.18) humans are placed at the core of the approach of the Team. At the scale of the neighbourhood and the community, they emphasize sharing and the exchange of energy production and services. There is some contrast between innovation and affordability, which leads to assuming incompatibility. The innovation understood in the scope of the technology could be limited by cost, but innovative ideas not always entail a budgetary restrictions. On the contrary, sometimes the most brilliant ideas can be very simple. In short, integrating certain philosophies into the Competition, making it evolve towards the solution of current problems leads to a more interesting Competition, producing excellent references, which can influence the whole sector: students, professors, researchers, professionals and industry. Sponsorship from innovative companies grows as does public interest in visiting the Solar Village. Since the media and social media are so important nowadays, it is an appropriate strategy to stimulate innovation, creativity and research. Innovation especially can arouse social interest.

Detailed information about the objectives of each prototype, the architectural design, the construction, materials and systems can be found on the web sites and in some specific publications.[7]

[7] SDE10 and SDE12

Website: http://www.sdeurope.org

solar
decathlon
europe

Systematically organised technical Information on the building design and construction of all SDE events are documented in the databases Smart Cities Information System (https://smartcities-infosystem.eu) and information about the individual houses is available on the Building Competition Knowledge Platform (www.building-competition.org), this platform's major activity is to secure the information, experiences and data from building energy Competitions such as the Solar Decathlon Europe and living labs worldwide. It is funded by the German Federal Ministry of Economic Affairs and Energy and assisted by an intensive information exchange with the organisers from the past events in Europe.

### 3.2.2 New technologies fostered by Competitions

Books (digitally available): *"Solar Decathlon 2010. Towards Energy Efficient Buildings"*; *"Solar Decathlon 2012. Improving Energy Efficient Buildings"*. Both books include a competition overview and a description of all the participating houses. SDE14, Website: *http://www.solardecathlon2014.fr*, Publication (digitally available): *"Project Profiles: Solar Decathlon Europe 2014."* SDE19, Website: *http://www.sde2019.hu*, *Publication* (digitally available): *"Visiting guide"*.

In order to mitigate global climate change, the intensive growth of sustainable design, energy efficiency and RES (Renewable Energy Sources) must be achieved especially in the building sector. In the Competition, the different solutions proposed through each house were clearly the result of a variety of approaches, responding to diverse climatic conditions and cultures. Therefore, all the houses placed special emphasis on passive design: the insulation, the thermal inertia, the ventilation and evaporative cooling, the shading systems, bringing back traditional techniques conveniently adapted to current needs. Once the energy demand is minimized due to an optimize architectural design, efficient appliances and equipment are used and then solar systems are integrated. Building Automation and Control Systems (BACS) and Building Energy Management Systems (BEMS) has been used in most of the houses.

The goal of sustainable energy use in buildings should not be to produce as much energy as possible, but to consume as little as possible. Therefore, the comfort conditioning is largely passive. The SDE has not only successfully confirmed that this goal is achievable, but even more, the houses, with their harmonized passive/active architecture/construction/HVAC/RES/smart-grid integrated energy efficiency, have opened up a new frontier for sustainable energy in buildings and the settlements of the future.

#### 3.2.2.1 Passive systems

All the participating houses included passive design strategies. Many of them achieved an excellent balance between envelope, orientation, geometrical aspects and other passive strategies. The results of the Passive Period implemented since the SDE12, show that the use of passive design strategies helped to maintain the interior comfort of the houses while consuming zero or very low energy.

Fifteen SDE12 houses were analysed to see if they could be classified as Zero Energy Buildings (ZEB). It was discovered that all of them had maintained a positive energy balance in both their annual energy simulations and during the monitored period during the Competition. If the annual energy balance of the houses is like the estimated one, they will not only be ZEB, but Net Plus Energy Buildings too.

These results should encourage the stakeholders of the building sector to introduce passive design into their promotions, not only to build sustainable buildings but also as a marketing tool and a better positioning in the market.

A wide range of conditions for sustainable building practices and solar energy, ready to be transfer to the market, were proposed: from cutting edge technologies to the very thoughtful use of passive solar strategies. For all the houses taking part in the Solar Decathlon Europe Competitions, architectural design considered an appropriate exploitation of solar gains. In high solar-radiation climates, the effect of the large amount of light and the usual lack of daylight control devices give rise to exterior sunscreen abuse, paradoxically generating artificially illuminated interior spaces. The daylighting and solar control integrated devices provide healthy and efficient interiors.

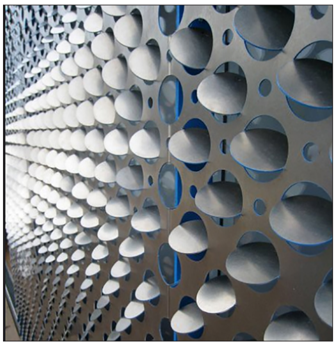


Figure 3.19: Lumen Haus. SDE10. Articulates the architectural space differently though combinations of sliding panels.

The benefits of daylight in the building sector are well known, the consequences of living in areas with not enough daylight go beyond the impact on electricity consumption. Solar energy technology is ready to be implemented. The winning house, from the Virginia Polytechnic Institute & State University (SDE10), Lumen Haus uses a series of mobile devices, enabling the exploitation or avoiding solar gains depending on both the indoor activity and the outdoor climate conditions. (Figure 3.19)

The Rosenheim University of Applied Sciences (SDE10), used solar protection based on zig-zag panels which, apart from allowing the control of solar radiation entering the house, contribute to its very interesting architectural design. (Figure 3.20). Solar protection devices can contribute to the high-quality design of windows and glass roofs. The RE: FOCUS, project of the University of Florida provides a good example (SDE10) (Figure 3.21). The design from Tongji University, the Para Eco-House space dynamically combines a vertical garden, shading, and a ventilation systemon the western facade. (Figure 3.22).

solar
decathlon
europe



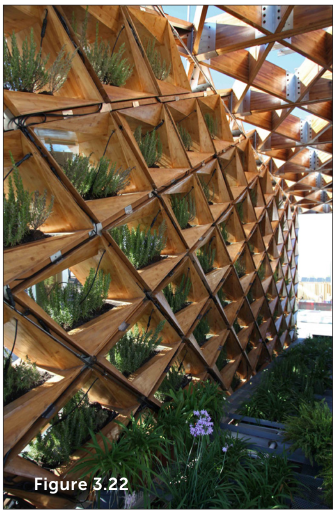



Figure 3.20: RE: FOCUS House. Solar Control Devices, SDE10.

Figure 3.21: RE: FOCUS House. Solar Control Devices, SDE10.

Figure 3.22: Para Eco-House space, combines vertical garden and shading, SDE10.

The optimal shape of the house is explored by some Teams, the FabLab House, from the Instituto de Arquitectura Avanzada de Catalunya suggested that 'form follows energy', they calculated the optimal solar envelope, which resulted in a paraboloid shape. The dwelling is not a machine anymore, but an inhabited organism. (Figure 3.23)

Figure 3.23: FabLab House. SDE10. Present the most efficient form to meet comfort conditions.

solar decathlon europe

Figure 3.24: Patio 2.12 Houses. SDE12. Contemporary interpretation of home spaces and traditional building technologies.

Figure 3.25. Med in Italy House. SDE12. Tradition and innovation are the two fundamental criteria behind its design.

Evaporative cooling is a key strategy for the cooling periods in Madrid. The Andalucia Team, with their Patio 2.12 House, has introduced an innovative cooling technology based on the principle of the botijo, a clay bottle popularly used in Spain to keep drinks cool. (Figure 3.24) Moreover, for the cooling periods, some of the houses took advance of the typical clear sky of Madrid and included night sky radiant cooling systems. The low-temperature radiant surfaces provide an efficient way to heat or cool buildings, especially if they have natural thermal sources as in the SDE12 houses. These systems were installed on the floor, on the ceiling, or in both places.

### 3.2.2.2 Thermal Energy Storage

Another key strategy is Thermal Energy Storage (TES), used both for cooling and heating periods, some being Sensitive TES systems (based on heavy materials such as concrete, stone or sand), and others Latent TES systems (based on the thermal storage capacity of Phase Change Materials (PCM)). From the earliest Competitions, the use of phasechange materials (PCM) was studied in most of the prototypes, contributing non-structural high thermal inertia and significant storage capacity to the thermal treatment systems. Therefore, compared to the SDUS05 Competition, in which only little PCM use was observed, the SDE12 Competition was a confirmation that these materials provide a solution as they have already gone through the experimental phase. In the 2012 Competition, the PCM were used in both passive and active applications. The Rome Team, with Med in Italy House, an indoor/outdoor house designed for a Mediterranean climate, whose layered walls contain sand in aluminium tubes and coatings of natural insulation, is designed to ensure a thermal balance. (Figure 3.25)

Figure 3.26: Napevomo House. SDE10. Innovative electricity domestic hot water (DHW) co-generation systems.

Figure 3.27. RE: FOCUS House. SDE10.


Figure 3.26

Figure 3.27

### 3.2.2.3 Solar energy Integration

The students' attention was drawn not only to designing and building houses, but also integrating technology to build 'homes'. Searching for new ways to improve the construction and integration of the building's solar components and systems, they use new approaches to engineering, to generating knowledge on sustainable solar buildings, and to reduce the waste and energy consumed during manufacturing. The Solar Decathlon Europe houses make an extensive use of solar-PV energy, ranging from flexible panels integrated into the building, as in the case of the Instituto de Arquitectura Avanzada de Cataluña (SDE10) (Figure 3.13), to concentration systems that enable the generation of electric power and domestic hot water (DHW), as in the case of the house presented by the Arts et Métiers Paris Tech, Napevomo House (Figure 3.26).


Figure 3.28

The University of Florida (SDE10), RE: FOCUS House used tubular photovoltaic modules (Figure 3.27). Apart from fulfilling a solar protection function, they can be integrated into the facade, while generating electric power. The Virginia Polytechnic Institute & State University used bi-facial PVmodules whose inclination is adjustable. CEU University (SDE10), and the SML House, used slim-layer PV-modules integrated into the facade (Figure 3.28).

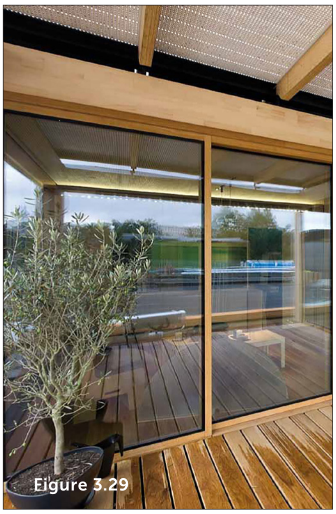


Figure 3.29

Some Teams also used solar energy to produce domestic hot water. Some of them came along with very innovative solutions, like the hemispherical collectors proposed by the Instituto de Arquitectura Avanzada de Cataluña (SDE10) (Figure 3.23). Building Integration Photovoltaics (BIPV) has been an inspiring constant in most of the proposals, and one of the key drivers for innovative successful and attractive houses. The photovoltaic system of the ECOLAR-house from the University of Applied Sciences Konstanz is the main feature of the building, visible throughout the design (Figure 3.29). The photovoltaic design therefore aims to integrate the modules into the construction, and they developed a mixed photovoltaic and thermal solar system. From Hochschule für Technik Stuttgart, Home+, the roof and facades are visually connected using different colours for the cells, forming a unique 'pixel design'. (Figure 3.30).

Figure 3.28: SML House. SDE10.

Figure 3.29: ECOLAR House. SDE12.

Figure 3.30: Home". SDE10

Figure 3.31: Omotenashi House. SDE12

Figure 3.32: Mor House. SDE19

The Omotenashi House, From Chiba University (Japan), uses roof tile-shaped solar panels. They are highly efficient but do not take away its quiet dignity, characteristic of Japanese housing. (Figure 3.31). The MOR House, from Delft University of Technology integrates tile-coloured solar panels into the façcade; they are reduce designed for easy assembly/disassembly, serving a practical and aesthetic function. (Figure 3.32)


Figure 3.30


Figure 3.31


Figure 3.32

The adoption of hybrid panels in some of the houses deserves a special mention. These panels were used for generating electricity and hot and cold water. The system is simple; a water plate is placed over the PV panels to improve their performance. The hot water generated is stored to be used later. During the night the process is repeated, however, in this case, the cooling of water is brought about through space irradiation, and the cool water is used for indoor air conditioning: directly or through the PCM accumulators.

### 3.2.2.4 Heat recovery

The SDE houses included commercial or custom-made heat recovery systems to reduce the heating and cooling loads for ventilation. In their functioning, thermal energy is exchanged through moving currents, typically air, which enters and leaves the house. The entrance air is pre-heated or precooled without the use of energy from heating or cooling equipment.

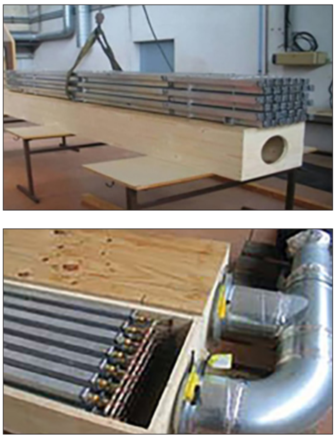


Figure 3.33: Phase Change Material based air tempering system. Detail of the closed ducts system. Napevomo House. SDE10

### 3.2.2.5 Building Automation and Control Systems (BACS) & Building Energy Management Systems (BEMS)

Building Automation and Control Systems (BACS) and Building Energy Management Systems (BEMS) played a decisive role in most of the houses, providing an efficient energy demand management. With some of them, it is also possible to know the energy production and consumption of the house in real-time, obtain advice on the operation of active systems as well as information aimed at improving the energy consumption habits of the occupant.
User-centred technologies were implemented in most of SDE19 houses. Like IoT technology through apps, smarts phones connect houses with their users, activating systems anticipating the arrival of the users to their homes or speech-based emotion detection.

solar
decathlon
europe

### 3.2.3 New concepts fostered by Competitions

Projects also focus on building sustainable energy communities. These new urban and social approaches of the European Competition were fostered by the inclusion of the ‘Urban design & transportation’ contest in 2014 and the ‘Neighbourhood integration and impact’ in 2019 whose result is a richer conceptual approach to the architectural design. This changes the understanding of architecture as a transforming element of the environment, gaining a great prominence in each of the proposals, and provides singular solutions to different cities and countries. A great distinctive character is present in each of the prototypes.


Figure 3.34: CANOPEA house. SDE12.

#### 3.2.3.1 Urban approach

The Rhône-Alps Team, with CANOPEA House, was the first SDE House to introduce a very interesting solution, pertinent to an urban environment. They built a prototype, which could be stacked one on top of the other, up to six storeys, presenting a real alternative and a very practical solution for limited urban spaces. While most submissions thoughtfully considered the modularity of their homes, the Rhône-Alps Team really applied this concept to the extreme which led to them being awarded honourable mention on sustainability and being the overall winner of the SDE12 Competition. (Figure 3.34)

In the SDE14, fourteen Teams explored the intervention in specific existing urban environments, proposing symbiotic relationships between new and existing structures. Team Prêt-à-Loger, in the SDE14, with the Home with a skin project propose a new housing typology for retrofitting typical Dutch terraced houses by adding a new skin on top of existing buildings (Figure 3.35). The Plateau Team, with the SymbCity project calls for the ‘colonization’ of rooftops, creating a harmonious additional floor (Figure 3.36).

The OnTop project, from the University of Applied Sciences of Frankfurt, consists of new housing typologies on top of buildings to densify cities by analysing the growth of city populations. (Figure 3.37)




Figure 3.35: Home with a skin. SDE14.

Figure 3.36: SymbCity House. SDE14.

Figure 3.37: On Top, SDE14.

In next Solar Decathlon Europe (SDE21), in Wuppertal (Germany), the urban aspect becomes mandatory for all Teams by considering further building of existing buildings.

solar
decathlon
europe

### 3.2.3.2 Resilient design, neighbourhood integration and impact

In 2014, resilient design gained prominence for the first time in the SDE. Universities from Mexico, Chile, Costa Rica, Japan and Thailand focus on solving or minimizing the effects of natural disasters, by showing the climate emergency already present in some parts of the planet. Ecology is certainly important, but it does not matter much if a building becomes uninhabitable due to flooding, earthquake, power outages or other natural disasters.

Adaptive house (Bangkok, Thailand) can survive minor earthquakes, storms and floods. A cluster of such houses could create a sustainable and adaptive village. (Figure 3.38) Project RenaiHouse from Team Chiba (University Japan), proposes a solution for rebuilding Fukushima area after the 2011 tsunami disaster. (Figure 3.39) Project Casa FENIX (Valparaiso & La Rochelle Universities) is a post-earthquake sustainable housing unit composing a sustainable community for relief. (Figure 3.40)


Figure 3.38


Figure 3.39


Figure 3.40

**Figure 3.38: Adaptative House. SDE14.**

**Figure 3.39: RenaiHouse. SDE14.**

**Figure 3.40: Casa Fenix. SDE14.**

In SDE19, actions have been introduced in territories that go beyond a purely urban environment, focusing on the social impact of the proposals, proposing solutions to a variety of starting conditions. Over4 Team, (Technical University of Civil Engineering of Bucharest) developed a renovation project of a condominium built in the communist era in Romania (Figure 3.41). The goal of the AZALEA Team (Polytechnic University of Valencia) is to preserve an orchard in Valencia and its typical house, the ‘barraca’. This typology works as a nexus between urban and natural living (Figure 3.42). The SOMEshine Team (University of Miskolc, University of Pécs and University of Blida) use the simple ideas of the vernacular Hungarian architecture to address the renovation of 800,000 outdated houses. The project places emphasis on social integration (Figure 3.43).

**Figure 3.41: Over4. SDE19.**

**Figure 3.42: AZALEA. SDE19.**

**Figure 3.43: Hungarian Nest +. SDE19.**


Figure 3.41


Figure 3.42


Figure 3.43

solar
decathlon
europe

Figure 3.44: TO House. SDE19.

The impact of behaviour of the users is also explored in the SDE, the TO Team (University of Catalonia) proposes a physical and social space that allows the inhabitants to reflect on how their behavioural habits relate to sustainability with the aim of triggering an ecosystem change, proposing a revision of daily activities and ways of living and of the Inhabited spaces that are Inherit from the past. (Figure 3.44) The philosophy behind the projects has become more powerful in the more recent editions of the SDE. Sometimes it can be seen that the motivation and creativity of the students is linked more to the resolution of social problems than to winning the Competition.

### 3.2.4 Successful showcases with influence in the market

The nature of Solar Decathlon Europe, designing, building and competing with houses, underlies the intention of prototypes to be not just good intentions, but a catalogue of actual, practical solutions leading towards, in many cases, to specific market applications. In order to mitigate global climate changes and their increasingly destructive consequences, it is imperative to further develop solutions. Solar Decathlon Europe has opened a new frontier for sustainable energy in buildings and the settlements of the future. The Solar Decathlon Europe showcases some of the strategies and main trends that have been developed in the last decade. Citizens are the final client. The visitors the Solar Villages found the prototypes interesting, not just experts, but especially ordinary people. They attended Solar Villages in droves during the Competitions, something exceptional for an exhibition about building and architecture. This social interest is one of the most relevant aspects of the Competition, since it allowed a wide audience to witness the fact that energy self-sufficiency and sustainable houses are possible in daily life. Beyond abstract approaches, it showed the broadest public that architecture is ready to merge with technology, offering specific, operative solutions. Beyond this, the activities, exhibitions, and specific messages to promote the change of behaviour of the users to favour more sustainable buildings and cities, has generated a social awareness in the visitors that will have a positive impact on their daily habits.

The houses now located around the world continue to serve numerous research projects. Some are being monitored and occupied used as Living Labs, thus generating additional knowledge; in the some of these houses technologies are being tested for longer periods. Qualitative and quantitative research is also being conducted optimised and tested by the user getting closer to the market. Other houses are used for educational purposes, or by sponsors as demonstrators and training centres, or in the universities as useful spaces or by administrations for community-oriented functions. Some of the living labs that operate in Europe today, have their origin in the previous participation in Solar Decathlon Competitions, both in the SDE and the SDUS. Among others, good examples of houses use after the SDE Competitions are:

- Used as a Living Lab for educational purposes.
- For dissemination and awareness purposes.
- Used as showrooms for technologies, systems and devices.
- Dedicated to research purposes, forming experimental prototypes in which research projects have been developed.

solar decathlon europe

### 3.2.4.1 Houses in Spain

(Universidad Politécnica de Madrid, UPM)
(Universidad Politécnica de Cataluña, UPM)


Figure 3.45


Figure 3.45


Figure 3.47

Figure 3.45: Magic Box. SDUS05.
UPM. ETSIT (UPM), Madrid.
(Research and educational use)

Figure 3.46: LOW3. SDE10. UPC.
Now Oficina Sant Cugat Sostenible
Plaça Barcelona, 15
Sant Cugat del Vallès (Social use)

Figure 3.46: CASA SOLAR. SDUS07.
Campus de Montegancedo.
(UPM) Madrid.
(Research and educational use)

solar
decathlon
europe

### 3.2.4.2 Houses in Germany


Figure 3.48.1


Figure 3.48.2


Figure 3.49

Figure 3.48.1 (SDUS11) &
Figure 3.48.2 (SDUS09):
"Lichtwiese campus of the TU"
City of Science Darmstadt,
Metropolitan Frankfurt
Rhine-Main Region.
(Research and educational use)

Figure 3.49:
Team IKAROS Bavaria. SDE10.
B&O Parkhotel
Dietrich-Bonhoeffer-Strasse 31
83043 Bad Aibling - OT Mietraching
(Hotel)

solar
decathlon
europe

### 3.2.4.3 Houses in France


Figure 3.50

Figure 3.51

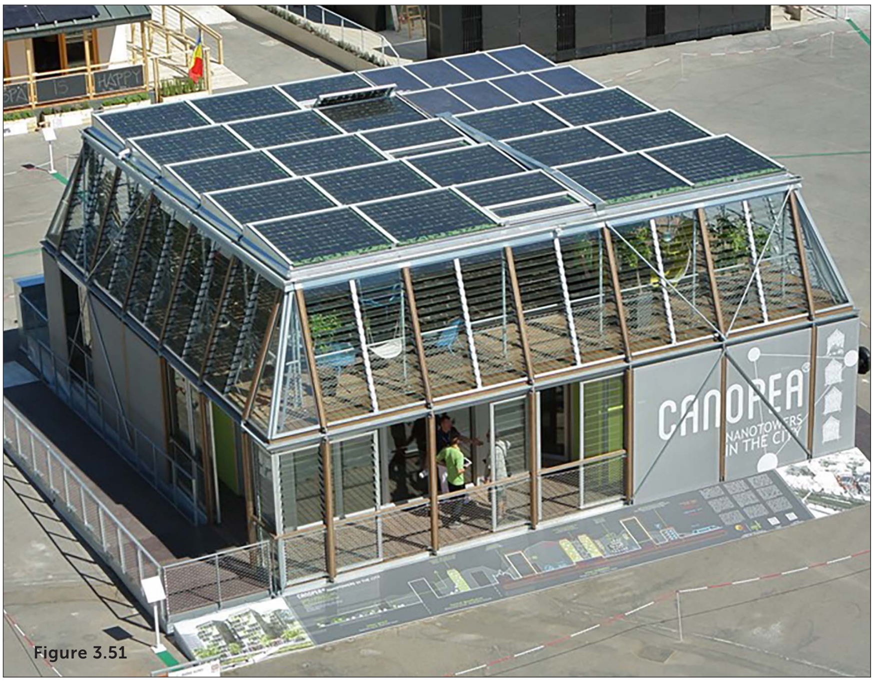


Figure 3.51

Figure 3.50: Napevomo House. SDE10.
(Arts et Metiers Paris Tech &
Bordeaux Univ.)
Arts et Métiers ParisTech -
Campus de Bordeaux
University in Talence, France
(Research and educational use)

Figure 3.51: Armadillo Box. SDE10.
Les Grands Ateliers Innovation
Architecture (GAIA): a technical
platform initiated by ENSAG and built
by the French government
and Saint-Etienne national school
of Architecture (ENSASE).
(Research and educational use)

Figure 3.52: Canopea. SDE12.
Armadillo Box. SDE10.
Les Grands Ateliers Innovation
Architecture (GAIA): a technical
platform initiated by ENSAG and built
by the French government
and Saint-Etienne national school
of Architecture (ENSASE).
(Research and educational use)

solar
decathlon
europe

### 3.2.4.4 Houses in United Kingdom (University of Nottingham)

Figure 3.53

### 3.2.4.5 House in Belgium (Ghent University)

Figure 3.54

Figure 3.53: The Saint Gobain Nottingham H.O.U.S.E. SDE10. Creative Energy University Park Campus University of Nottingham (Research and educational use)

Figure 3.54: E-CubeHouse. SDUS11. Greenbridge Science Park Oostende, Belgium

solar
decathlon
europe

3.2.4.6 House in Switzerland
(École Polytechnique Fédérale de Lausanne, School of Engineering and Architecture Fribourg, Geneva University of Art and Design, and the University of Fribourg)

Figure 3.55: NeighborHub. SDUS17.
blueFACTORY Fribourg
Passage du Cardinal 1
CH-1700 Fribourg, Switzerland

Figure 3.56: LISI House. SDUS13.
Nám. Sítná 3105
272 01 Kladno 2

Figure 3.55

3.2.4.7 House at Czech Republic
(Czech Technical University)

Figure 3.56

solar
decathlon
europe

### 3.2.4.8 House in Austria
(Vienna University of Technology)

**Figure 3.57: Selficient. SDUS17.**
**Blaue Lagune Parz.**
**2334 Wiener Neudorf**
**Austria**

**Figure 3.58: AIR House. SDUS13.**
**Utrecht Science Park**
**Bolognalaan 99**
**Utrecht, The Netherlands**

Figure 3.57

### 3.2.4.9 House in Netherlands
(HU University of Applied Sciences Utrecht)


Figure 3.58

### 3.2.5 Research, innovation and market opportunities.

Promoting innovation and generating knowledge to improve the performance of energy-efficient buildings and transferring this knowledge to industry and professionals is one of the main goals of Solar Decathlon Europe. Research and innovation can be found at different levels of maturity in the Solar Decathlon Europe Competition. It is a university Competition, so behind each proposal there are fresh ideas, enthusiasm, creativity and energy developed by students and professors (in their early stages of development) which are built and/or monitored for the first time during the Competition. More mature systems developed in university research centers are also implemented in many prototypes, using them as real life demonstrators and test facilities.

The Solar Decathlon Europe is also an event highly supported and sponsored by companies, the companies use the houses as demonstrators of cutting-edge products already available in the market. Companies are also interested to come in touch with student as possible future employees. Solar Decathlon Europe sponsors are mainly building materials and products and equipment manufacturers, broaden the focus towards promoters, and other relevant stakeholders like the tourist sectors could increase the market viability of Solar Decathlon Europe solutions. With regard to research, the Solar Decathlon Europe was organised by the UPM in 2010, and 2012, and by research centres in SDE14 (CSTB) and SDE19 (EMI). In all cases the organisation had an interest in promoting research, coinciding with the Teams' own interests. From 2010, there has been an intention from the Organisers to encourage the creation of shared research. Links were established during the Competitions that still exist today and have generated new projects and initiatives. Books, scientific articles, PhD theses and conference papers were produced by each university.

Industrialization and market viability are contests incorporated into the Competition to close the gap with the market, encouraging Teams to be creative in this area. The approach is very different from one Team to another. Many Teams proposed prototypes with innovative industrialization systems. It is worth mentioning the Team from Andalucía in the SDE12, whose Patio 2.12 House is a prototype exploring an innovative concept consisting of living prefabricated modules with clear marketable potential. Other Teams with designs inspired by their local traditional buildings, for example the University of Architecture and Urbanism & Technical University of Civil Engineering of Bucharest & University Politehnica of Bucharest Team, and the Universitá degli Studi di Roma TRE & Sapienza Universitá di Roma & free University of Bozen & Frauenhofer Italy Team in the SDE12, understood standardization as adjusted and set up for centuries and in a spirit which could be transposed into a modern house.

In the SDE14 many innovative proposals were linked to marketable opportunities. For instance, the proposals from the University of Applied Sciences of Frankfurt, or the Universidad de Alcalá (Madrid) with the development of industrialized modules for the retrofitting of typical existing collective buildings. The proposal from France's Team Phileas in Nantes, to retrofit an historical Landmark on the Loire River bank, within an urban renewal project based on urban agriculture. The prototype represents an apartment with greenhouses on the top floor. The Technical University of Delft proposed an industrialized skin for the retrofitting of a typical Dutch terraced house, which could also have great potential on the market.

solar
decathlon
europe

[8] "Solar Decathlon 2012. Improving Energy Efficient Buildings", words of Susana Torre, Jury of Architecture in SDE12.

*"Some dwellings in the exhibition also showed that we are still trying to work out old ideas. For example, those of Dr. Maria Telkes, the M.I.T. pioneer scientist who invented the first solar panels to be used in a house in 1948 collaborating with architect Eleanor Raymond in attempting to integrate the new-fangled technology into a vernacular architectural language. These examples remind us of how long it takes for ideas – even good ideas – to influence and change the modus operandi of industries, academia, and, more importantly, the public and private agents that build and change the physical environment."* [8]

In the SDE19, most of the proposals were conceived to preserve important elements of the urban environment or to solve current social problems in our cities. The houses with a strong social component should not be analysed in terms of economic viability, as their benefits are wider. Their scope is territorial. Concepts like sharing and coexisting are very interesting for future intelligent living, however sustainable intelligent cities must consider the integration of the habitant as an active member in society as opposed to the current growing individualization of society.

Innovation now tackles social and complex issues. The social impact of some of the proposals if they were to be implemented would be substantial. Administrations are key drivers here. Some of the innovative ideas could be applied in European social housing and neighborhoods such as 'Lighthouse' projects, exploring their implementation in the market, revitalizing vulnerable areas and attracting private investment. The EIP-SCC Marketplace would be interested in helping to deliver investments for new sustainable business models based on the optimization of urban space and on attractive initiatives to encourage the repopulation of rural areas and the revaluation of the rural environment.

**Figure 3.59: Casa Solar. SDUS07. Visit of the President of the Spanish Government and two Ministers.**

### 3.2.6 Policy makers

Solar Decathlon Europe Organisers have had the capacity to link the interest of governments, the private sector and universities in the achievement of shared common goals. Policy makers are the engines of the system. They need to be aware and involved to achieve substantial changes. In the communications strategies of the different SDE Organisers, an effort has been made to catch the attention of policymakers. Policy makers are already working to achieve a future sustainable society, specifically in building in which there have been substantial changes in the last decade. The Energy performance of buildings directive and its recast (EPBD - 2010/2012/2018) is, together with the Energy Efficiency directive (2002 and 2011), the main legislative instruments that have been able to promote the energy performance of buildings and boost renovation within the EU. Nevertheless, the real implementation in the member states of the EU is slow, and more needs to be done.

The quality and level of maturity of the research and innovation involved in the Solar Decathlon Europe is diverse, but certainly it goes from the exploration of ideas to the demonstration of cutting-edge, market ready strategies and technologies towards nearly zero, net zero and energy plus buildings. However, all the proposals contain interesting items to be explored and whose implementation would contribute to more sustainable buildings and cities. Unfortunately, when the Competition finishes it is also the end of the road for some of these ideas and solutions.

The degree of development and impact on the market could easily be higher with greater institutional involvement. But not only that, the public administration can also indirectly incentivise and attract private investments to reinforce sustainable development.

Policy makers could accelerate the SDE technological innovation to reach the market by helping the universities to access tools that already exist in the EU, for example in the Horizon Europe program. However, in the last editions of the Solar Decathlon Europe there has been an interesting change, now innovation is being used to tackle social and territorial items. The social impact of some of the proposals, if they were implemented, would be substantial. Public administrators are key drivers here, not only because they could be the promoters for some of some ideas but also because to implement some of them (sharing and coexisting, common spaces, rooftop modules, façade modules) changes need to be made in local Urban or Building Regulations.

The Solar Decathlon Europe Organisers have already worked on the setting up of interesting partnerships, the presence of politicians and high representatives from different states in the Solar Decathlon Europe have been notable. There have been multiple visits by ministers, officials of all kinds, to the various Solar Villas in Spain, France and Hungary with multiple presentations in international forums and at trade shows in different countries in the presence of senior officials from different countries from the European Union and the United States and elsewhere.

Among the events organised in Spain with Casa Solar (Prototype of the SDUS07 from UPM Team) to raise society awareness, multiple visits were made by Ministers, Mayors, and the Spanish Prime Minister (Figure 3.59) who visited the house in the 'España Solar' event with two Ministers from the Spanish government. The awareness of the politicians led to the involvement of the UPM, and whose support was necessary to reach the agreement with DOE to organize the first and second Competitions in Europe.

Figure 3.60: Visit of Prince Felipe, (current King - Head of State of Spain) with the Ministry of hosing, SDE10.

Figure 3.61: Visit of the EU Ministers of Housing summit in the Solar Decathlon Europe 2010 Solar Village


Figure 3.60


Figure 3.61

In the SDE10 Competition, the current King and Queen of Spain visited to the 'Villa Solar' (Figure 3.60). Several ministers (Housing, Energy, Environment and infrastructure), the president of the Regional Government of Madrid, the president of the Regional Government of Extremadura, the president of the Regional Government of Aragón, the president of the Generalitat de Catalonia, together with the mayors of Madrid and Barcelona among others also visited. There were also numerous Secretaries of State, Technical General Secretaries and General Directors present. The visit to the Solar Village of all the Housing Ministers of the European Union (Figure 3.61) was especially interesting.

solar
decathlon
europe

Figure 3.62: Mayor of Versailles, Francois de Mazieres. Opening ceremony of SDE14.

Figure 3.63: President of Hungary visit to SDE19.


Figure 3.62


Figure 3.63

In the SDE14, the Mayor of Versailles, Francois de Mazieres opened the Welcoming Ceremony (figure 3.62) and the President of the Palace of Versailles, Ambassadors from different participating countries and the Minister of Housing and Territory Equality each visited the Solar Village. In the SDE19 the President of Hungary and the Minister of Innovation and Technology (figure 3.63) visited the Solar Village.

There have also been contacts at the highest level between the European Commission and the US Government, with an exchange of letters between the Secretary of Energy and the European Commissioner of Energy concerning the Solar Decathlon Europe. The EU-U.S. Energy Council was held in Washington the 28 November 2011, with the participation of US Secretary of State, Ms.Clinton, and US Secretary of Energy, Mr. Chu, EU High Representative, Ms. Ashton and the EU Commissioner for Energy, Mr. Oettinger. The Joint press statement says *The EU and the U.S. intend to co-operate on continuing the Solar Decathlon Europe Competitions, transforming them into an initiative to foster sustainable economic development by creating markets on both sides of the Atlantic for integrating innovative technologies and renewable energy sources into new and refurbished low impact buildings.*

Politicians, celebrities and decision makers have all visited the different Competitions, including Ministers, Regional Government members, Mayors, Ambassadors, Parliamentarians, members of the European Parliament and Senior Officials from the European Union.
Solar Decathlon Europe Organisers attended several meetings and events in Europe with EU High representatives, with the Commissioner for Energy of the European Union (presented the Communications prize at the Sustainable Energy Week), several senior officials from the D.G. Energy of the European Union such as the Director of Renewables, Innovation Research, and Energy Efficiency, several Ministers from the French Government (Minister of Energy, and Minister of Environment), Minister of Innovation and Technology of the Hungarian Government, numerous senior officials from the Governments of France, Hungary and Germany. Solar Decathlon Europe Organisers have been working on the establishment of partnerships since 2002, and it has been a pertinent and valuable strategy, aligned with The Sustainable Development Goals (SDGs) since 2015, when UN countries adopted the 2030 Agenda, specifically, with the SDG 17 'Partnership for the Goals'.[9] The Solar Decathlon Europe strategy has been successful, but more needs to be done. Now, as stated in the SDG 17, *"Urgent action is needed to mobilize, redirect and unlock the transformative power of trillions of dollars of private resources to deliver on sustainable development objectives."*

[9] SDG 17 "Partnership for the Goals": A successful sustainable development agenda requires partnerships between governments, the private sector and civil society. These inclusive partnerships built upon principles and values, a shared vision, and shared goals that place people and the planet at the centre, are needed at the global, regional, national and local level.

solar
decathlon
europe

## 3.3 professionals & industry involvement

The Solar Decathlon Europe Competition relies on the involvement of industry. No Competition could have been organised and no Teams would have participated without the sponsorship from industry. Industry has voluntarily sponsored the SDE organisation, University Teams and the testing of innovative building products in all of the Solar Decathlon Europe editions. Valuable partnerships with industry have been established between universities and industry and between the organisers and industry.

The Solar Decathlon Europe communications strategy has considered professionals from the construction sector as key drivers towards the decarbonization of the building sector. They need to be aware, but they also need to know which sustainable and cost-effective solutions and tools are available to be used and to be prescribed in their projects. Specific activities were organised; professionals participated in conferences, workshops, and courses developed during the Competition together with wide number of visits to the houses. There was also a relevant participation of experts from different fields involved in the Organisation of the Competition: during the design phase, the Competition phase and for the organisation of the event itself.

### 3.3.1 Professional participation and awareness

More than 25 000 professionals from the construction sector participated in conferences, workshops, and courses developed specifically for this group. Approximately 469 000 professionals visited the International Trade Fairs where the SDE was present. Five Conferences for professionals were organised with 1 500 professionals attending. During the Solar Decathlon Europe Competitions, thousands of professionals have visited the houses both during the assembly process, and the Competition, with technical tours organised for them in every edition. The organising teams have been mainly made up of students, researchers and professors from the Universities and research Institutions. Nevertheless, for the development of specific tasks, the organisation relied on the work and experience of many professionals from all three Organisation Areas: Competition, Infrastructure and Communications.

In the Organisation team professionals oversaw administrative tasks, the drawing up of the Rules and regulations, the revision of Team's deliverables and communications with the Teams. Specifically, in the assembly phase, experts oversaw the inspections of the houses and the Solar Village to ensure compliance with Building and Urban Regulations. During the Competition Phase Juries were made up of eighteen national and international professionals of renowned prestige. It is worth mentioning the participation of the Pritzker Architecture prize winner Glenn Murcutt, who was a member of both the Architecture Jury of first Solar Decathlon (2002) and of first Solar Decathlon Europe (2010).

*"Having been a member of the first Solar Decathlon held in Washington D.C. in 2002, I can confirm that the standard of design reached in this Solar Decathlon exceeds the quality achieved in Washington by a large measure. It has been an enormous improvement."* [10]

[10] "Solar Decathlon 2010. Towards Energy Efficient Buildings"; the words of Glenn Murcutt, (Architect and winner of the 1992 Alvar Aalto Medal, the 2002 Pritzker Architecture Prize and the 2009 American Institute of Architects Gold Medal).

solar
decathlon
europe

In order to link professionals and industry with the Competition, extra-Competition awards are proposed to associations or professional groups. These prizes enrich the scope of the Competition, in some cases evaluating aspects relevant to connect technologies and prototypes to the market. Contests like Interior design, Lighting design and in other cases evaluating aspects that, although important, the official contests do not contemplate, like accessibility, building sustainability certification (VERDE), SDE prototypes meeting the standards for social housing. These awards were supported by associations such as the Association of Lighting Professionals (APDI), the ONCE Foundation (Spanish organisation for blind people) and the Spanish Committee of Representatives of People with Disabilities (CERMI), the Green Building Council Spain and the European social housing agency CECODAS. Extra-Competition juries were also experts of renowned prestige.

The Solar Village infrastructure required the collaboration of numerous professionals: the electrical infrastructure project and implementation, the environmental lighting project and implementation and the optical fibre infrastructure and telecommunication project and implementation. These works were coordinated in the SDE Organisation in collaboration with the local administration and several companies in the sector.

### 3.3.2 Synergies from industrial participation

In the Solar Decathlon Europe 2010 and 2012 two levels of sponsorship management coexisted, perfectly coordinated with each other: Fiscal Sponsorship (associated with tax exemptions) and Non-Fiscal Sponsorship. The organisation contacted more than 150 companies, of which 56% showed interest, resulting in signed Fiscal Sponsorship agreements with 6% of them.
The five Sponsor companies were:

1. SAINT GOBAIN (Principal Sponsor).
2. SCHNEIDER ELECTRIC (Strategic Sponsor).
3. KÖMMERLING (Sponsor).
4. ROCKWOOL (Sponsor).
5. FCC (Sponsor).

As a summary of the non-fiscal sponsorship, throughout the months of the project's development, commercial contacts were maintained for in-kind or financial contributions, more than 60 different SMEs made different kinds of significant contributions.

In the Solar Decathlon Europe 2014, the sponsors were structured in five categories:

1. Diamond partners: Schneider Electric, Total, ADEME
2. Gold partners: Monoprix, Bouygues Construction, Serge Ferrari
3. Silver partners: Caisse des Dépôts, Air Liquide, Tôlerie Forezienne, ERDF , Freevox
4. Bronze partners: Qualitel, Forbo Flooring Systems, Groupe Betom, JBL, Nemetschek, Lafarge, FOSELEV, Bubendorff, Rockwool, Ciments Calcia, Phébus, BMWi, Raboni, Yves Cougnaud, Husson International, PICBOIS, E.V.A, Bureau Véritas
5. And 59 institutional partners

solar decathlon europe

In the Solar Decathlon Europe 2019, the sponsors and funding Institutions were structured in six categories:

1. Main funding institutions: Hungarian Government, Ministry for Innovation and Technology.
2. Diamond level sponsor: Tungsram Group
3. Gold level sponsor: Still, WHB Group, ÉPKAR,
4. Silver level sponsor: Layher, Makita, Nemzeti Közművek, Algeco, Confector
5. Professional sponsor: Kék Bolygó Klímavédelmi Alapítvány, Környezetvédelmi Szolgáltatók és Gyártók Szövetsége, Hungary Green Building Council, Hungarian Association for Innovation, Építési Vállalkozók Országos Szakszövetsége
6. Bronze level sponsor: DMRV, DR. POWELLS' CLINIC, Teqball

The repercussions of synergies from industrial participation goes beyond the Solar Decathlon Europe Competition and prototype technologies. In several instances, the links have become solid. The Solar Decathlon Europe is a very intense experience for all stakeholders involved, including industry, and the links have lasted over the years, generating further collaboration in other research and development projects. An atmosphere of trust and generosity has been created in the Solar Decathlon Europe, with the links being maintained in many cases. The presence of some industrial partners in the university has been reinforced and vice versa, common goals are being pursued. This is a reality in university Teams as well as in the Organizer Teams. As an example, UPM links with Saint-Gobain and Kömmerling (the SDE10 and SDE12 sponsors) have led them to becoming partners in two national research projects focusing on building retrofitting and comfort conditions (SIREIN Project and BALI Project, http://investiga.dcta.upm.es/sirein/; http://investiga.dcta.upm.es/bali/). The transfer of knowledge has also been encouraged from university to industry, with university professors being invited as speakers in communications events, and from industry to universities when technicians from the industry participate in Master classes's at the university. The links established in the Solar Decathlon Europe are somewhat fragile, since they rely on the specific people (professionals, students or professors) who are in contact during the period of the Competition. Preserving these links in time and expanding them towards more members of institutions and companies is an interesting way of reinforcing the Impact of the Solar Decathlon Europe.

We have chosen the words and reflections of the main sponsors of the Solar Decathlon Europe 2010 to illustrate the synergies between Solar Decathlon Europe and industry:
*"The Competition was a great occasion to bring to the public innovative technologies and design strategies for buildings – all that in a very beautiful environment. Such technologies could also be tested and led towards original collaborations between the scientific world and the business sector. Several collaborative researches were conducted together with businesses. Solutions and outcomes from these researches were successfully applied to the Solar Decathlon Europe's prototypes which used, tested, and presented new products available on the market. As a result, the Competition encouraged similar initiatives from different organisations throughout Europe, therefore increasing the number of activities explaining the values we share with the Solar Decathlon Europe."*

*"Values for the future. The importance of the Solar Decathlon Europe 2010 Competition for the Main Sponsors"*

solar
decathlon
europe

The great goals of Solar Decathlon Europe together with its visibility and the exciting and emotional component of participating in a Competition places Teams in a good position to capture the interest of industry and get sponsorship. Sponsors are very interested in donating materials and equipment. Typical sponsors are companies focusing on PV and thermal Solar Systems, efficient and innovative HVAC systems, evaporative cooling systems, heat recovery systems, innovative lighting systems, thermal insulation, innovative glazing, sustainable building finishes, PCM, and Building Automation and Control Systems. Sponsors use Solar Decathlon houses as showrooms to present their new products. They make sure students know the specifications so they will explain it to the visitors (general public, professionals, politicians). In most of the houses it can be relatively easy to get innovative materials and systems, especially those whose visibility (like interior finishes, exterior finishes, furniture, façade material and of course PV and thermal panels). Companies are also interested to come in touch with student as possible future employees. That way the SDE servers, not only to prepare the next generation of future architects and engineers, but as a recruiting event.

The Solar Decathlon Europe is also a place at which links between industry and policy makers have been established. Again the atmosphere of trust that is generated around the event generates personal links that have facilitated subsequent negotiations between industry and government, which was an unexpected result of the Competition for some of the sponsors.

## 3.4 conclusions & lessons learned

The Solar Decathlon Europe Competitions have proven to be an effective tool with regards to social awareness of European citizens, as it is a useful way of promoting new knowledge and innovation in energy efficiency and sustainability in our buildings and cities. Transferring this knowledge to the market is possible, especially, if it is accompanied by specific strategies on how to influence European professionals and industry. The editions of the SDE Competitions have been highly successful, providing an internationally recognized added value with respect to the US editions, relying on Europe for sustainability, energy efficiency, innovation, and citizen awareness. In all the editions, the proposed general objectives have been achieved, although the social and professional impact has been uneven.

The SDE12 edition has had the greatest social and media impact in Europe. It was due to the planning of activities not only in Madrid, but in other European countries with the collaboration of Energy Agencies and universities from some countries through 10Action Project, and the active participation of the SDE10 universities in becoming a focus of dissemination and awareness to transform and improve their environment. 10Action has proven to be an excellent tool for facilitating the synergies generated by the Solar Decathlon Europe. To take advantage of the synergies linked to the Solar Decathlon Europe Competitions, a global strategy, further than the Competition itself, must be well designed and developed for every single target group, and many different activities must be implemented to have a successful impact.

### 3.4.1 Smart cities potential

The Solar Decathlon Europe Competitions have opened up a new frontier for sustainable energy in buildings, generating valuable knowledge for Smart City stakeholders. The European Innovation Partnership on Smart Cities and Communities (EIP-SCC) brings together cities, industries, SMEs, investors, researchers and other smart city protagonists. These partners work together in Action Clusters on specific issues related to smart cities. The six Action Clusters organize the Marketplace; the Solar Decathlon Europe Competition protagonists include cities, industries, SMEs, investors, researchers and the public. The Competition has generated knowledge and expertise in all these six Clusters:

i **SUSTAINABLE DISTRICTS & BUILT ENVIRONMENTS**

In order to mitigate global climate changes and the intensive growth of energy efficiency and Renewable Energy Sources, utilization must be achieved in the building sector. The Solar Decathlon Europe has successfully demonstrated solar system integration in the built environment.

ii **INTEGRATED INFRASTRUCTURES & PROCESSES**

A low-tension micro-grid was created in the Solar Decathlon Europe, that interconnected the houses and their solar panels, linking them directly to local and global grids and thereby helping to create net-zero energy homes (Net ZEB) and net zero energy clusters (Net ZEC), balancing the energy flows, and adapting the energy supply to the demand in real time.

solar decathlon europe

**iii SUSTAINABLE URBAN MOBILITY**

The Solar Decathlon Europe Solar Village Grid integrates Solar Houses, Organisation buildings and electric cars. The surplus energy obtained from the houses is used for Solar Village events and for transportation, that could happen in every district. Solar Decathlon Europe has also enhanced the awareness of citizens and new generations of young people towards public transport, bicycles and other forms of sustainable mobility.

**iv BUSINESS MODELS, FINANCE & PROCUREMENT**

The Solar Decathlon European Organisers each introduced some changes in the Rules and regulations to favour the attainment of the objective of evaluating Industrialization, market viability and affordability of the prototypes.

**v CITIZEN FOCUS**

The Solar Decathlon Europe and 10ACTION projects looked for ways to encourage behavioural changes in European citizens. More than 680 people (184 861 European citizens with 10Action) have learned, and thought about energy and sustainable issues, with specific activities for them, and more than four million European citizens have received news about the values promoted by these projects.

**vi INTEGRATED PLANNING, POLICY & REGULATIONS**

The institutional leadership was crucial for the Solar Decathlon Europe to fulfil its objectives. Solar Decathlon Europe Rules are aligned with European Directives and with the Sustainable Development Goals (SDGs). They encourage the reduction in energy consumption, the increase in building energy efficiency and the use of renewable energies. The Solar Decathlon Europe has strengthened and revitalised partnerships between universities, policy makers and the private sector. The current King of Spain, the President of Hungary ,the Spanish Prime Minister, many different Ministers from the Spanish, French, and Hungarian governments, all the Housing Ministers of the European Union, the President of the Regional Government of Madrid, ambassadors, mayors and high officials have all visited the Solar Villages of the different SDE Competitions.

To reach sustainable cities it is necessary to promote outreach projects, like the Solar Decathlon Europe. It has proved to be effective due to its global reach: increasing awareness in society, demonstrating and testing innovative sustainable technologies, providing creative urban and social solutions and strengthening essential alliances between all the stakeholders involved.

### 3.4.2 Communication potential

University competitions and the mobilization of universities to sensitize their environments on issues related to the improvement in energy efficiency and sustainability have proven to be an effective communications tool, both because of the creative capacity and for the enthusiasm transmitted by university students when they are motivated and actively committed.

solar
decathlon
europe

The SDE held in Madrid in 2012, was the most effective in terms of communications. An ambitious strategy was planned, which, facilitated by the 10Action project, allowed a professional, social and media impact that reached more than twelve European countries, expanding knowledge and activities to make people energy aware, promoting their change of behaviour, and to improve sustainable conditions of our buildings and cities. 220 000 people visited the Solar Decathlon Europe 2012, 67 activities took place, as well as debates, conferences, and students from more than 30 universities from all over the world visited the Villa Solar in Madrid.

It is extremely important to look for alliances when addressing children and teachers, because not every country has direct access to schools. It is not necessary to have a huge marketing budget, but it is important to select the appropriate channels of communication. Educational activities for children must be offered continuously, especially in those countries, in which teachers are looking for additional opportunities and educational materials.

The motivation of teachers makes all the difference for adolescents. The integration of the topic in the curricula or making continuous education in the area compulsory are necessary to achieve continuing impact on the target group. The collaboration with the Ministries of Education is necessary to get the topics of renewable energies and finite resources included in the school curriculum. A lot of time and effort was necessary to achieve collaboration with the Ministries of Education, especially in countries in which education is subject of individual federal states. Unfortunately, most of them were reluctant to transfer information on 10Action to their school contacts. The exhibitions of energy-efficient houses are an impressive way of informing professionals and public about new innovative technologies in a practical manner. From the feedback received, the exhibitions proved to be a significant tool for raising the energy awareness of European society. For this reason, projects like 10ACTION must continue to work closely with the Universities organising exhibitions for the general public.

The Conference-debate on ‘Nearly zero-energy buildings: new construction and refurbishment’ held in Madrid on May 24, 2012 during the GENERA 2012 Exhibition, was considered an innovative format (debate + broadcast online) which proved to be very interesting for the professional associations. In order to reach the largest possible audience, this event was attended by 714 professionals. The collaboration between the Universities and the local schools in order to establish continuous school visits to the exhibitions is very effective for the students. It is an interesting environmental tour that improves the students’ knowledge in energy issues. This is clear from the feedback received from exhibitions at which most visitors were children and young people.

The collaboration between SDE organisers and the EIP-SCC members, opens up another synergetic way of improving energy efficiency and sustainability awareness among European professionals and industry. It is certainly a key driver for future SDE editions that must be explored.

solar
decathlon
europe

### 3.4.3 Fostering innovation and transferring it to the market

The Solar Decathlon Europe Competition has evolved towards the solution of current problems, the houses are excellent references, which can influence the whole sector: students, professors, researchers, professionals and industry. Sponsorship from innovative companies' interest grows as does public interest in visiting the Solar Village. Since the media and social media are so important nowadays, it is an appropriate strategy to stimulate innovation, creativity and research.

In the Competition, the different solutions proposed through each house were clearly the result of a variety of approaches, responding to diverse climate conditions and cultures. Therefore, some houses placed special emphasis on their insulation, some on thermal inertia, and others on ventilation and evaporative cooling, bringing back traditional techniques conveniently adapted to current needs. Stakeholders from diverse climate zones and countries will find relevant solutions for their specific local circumstances in the SDE Competitions.

The student's attention was drawn not only to designing and building houses, but also integrating innovative technologies to building 'homes', searching for new ways of improving the construction and integration of the building's solar components and systems, using new approaches to engineering, to generating knowledge on sustainable solar buildings, and to reducing waste and energy consumed during manufacture.

All the participating houses included passive design strategies and energy-efficient systems. Many of them achieved an excellent balance between envelope, orientation, geometrical aspects and other passive strategies. Fifteen SDE12 houses were classified as Net Plus Energy Buildings. The nature of the Solar Decathlon Europe, designing and building houses and making them ready for competition, underlies the intention of prototypes to be a catalogue of solutions leading towards to concrete market applications. The Solar Decathlon Europe showcases some of the strategies and of the main trends that are being developed in the field today.

The houses, now located around the world, continue to serve numerous research projects. Some are being monitored and occupied and used as Living Labs, generating knowledge; other houses are used for education purposes, or by sponsors as demonstrators and training centres, or in the universities as useful spaces or by administrations for community-oriented functions.

The European Union should be interested in finding a way to get more out of the knowledge the Competition generates. The quality and level of maturity of the research and innovation involved in Solar Decathlon Europe is diverse, but it certainly goes from the exploration of ideas to the demonstration of cutting-edge, market ready technologies. The degree of development and impact on the market could easily be higher with greater institutional involvement.
But not only that, the public administration can also indirectly incentivise and attract private investments to reinforce sustainable development.

solar decathlon europe

78 Universities in 58 Teams from around the world have participated in the four Solar Decathlon Europe Competitions held to date. Over 400 researchers and PhD students participated in research projects, directly or indirectly associated with the Solar Decathlon Europe and 10Action projects. Some research output includes books, scientific articles, highlighting the Special Issue of Energy & Buildings, PhD theses, Conference Papers and Research Projects.

More than 25 000 professionals from the construction sector participated in conferences, workshops, and courses developed by the Solar Decathlone Europe and 10ACTION, and during the Solar Decathlon Europe Competitions, thousands of professionals have visited the houses both during the assembly process, and the Competition. Industry has voluntarily sponsored the SDE Organisation, university Teams and testing innovative building products in all Solar Decathlon Europe editions. Synergy between the SDE and the market is demonstrated by the involvement of sixteen industries, eighteen companies, 69 SMEs and 119 collaborators just in the Organisation of the event to which must be added those industries, companies and SMEs involved in the sponsoring of the University Teams.

Students, researchers and professors mainly make up the organising teams of Solar Decathlon Europe editions, nevertheless for the development of specific tasks, the organisation relied on the work and experience of many building industry professionals.

Innovation now tackles social and complex areas. The social impact if some of the proposal were implemented would be substantial. Public administrations are key drivers here, some of the innovative ideas could be applied in European social housing and neighborhoods as 'Lighthouse' projects, exploring its implementation in the market, revitalizing vulnerable areas, and attracting private investment. Public administrations could promote of some of the ideas, but they are also needed because changes in Local or National Building Regulations needs to be made to implement some of them.

The EIP-SCC Marketplace would be interested in helping deliver investments for new sustainable business models based on the optimization of urban space and on the attractive initiatives to encourage the repopulation of rural areas and the revaluation of the rural environment. Policy makers could accelerate the SDE technological innovation to reach the market by facilitating access to tools that already exist to the universities.

The Solar Decathlon Organisers have been working on the establishment of partnerships since 2002, the presence of politicians and high representatives of different states in the Solar Decathlon Europe have been notable. It has been a pertinent and valuable strategy, aligned with The Sustainable Development Goals (SDGs) since 2015, when UN countries adopted the 2030 Agenda, specifically, with SDG 17 'Partnership for the Goals'.

SDE _ THEMATIC REPORT _ 4/4 _

EDUCATION & WORKFORCE ENHANCEMENTS

*EC TENDER #: ENER / C2 / 2016-502*

# solar decathlon europe

# 4. education & workforce enhancements

*BEATRIZ ARRANZ, RICHARD AMARAL, SERGIO VEGA SÁNCHEZ*

*UNIVERSIDAD POLITÉCNICA DE MADRID*

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# table of contents

PG


| | | |
|---|---|---|
| | **Introduction** | **156** |
| **4.1** | **SD surveys and participatory research.** | **158** |
| 4.1.1 | Surveys in SD. Description | 158 |
| 4.1.2 | Surveys about education in SD. Description | 159 |
| 4.1.3 | SDE 2020 survey. Description | 160 |
| 4.1.4 | Semi-structured interviews | 161 |
| 4.1.5 | General information on the profile of the respondents | 162 |
| **4.2** | **SDE educational assessment** | **166** |
| 4.2.1 | SDE underlying objective: education of university students | 166 |
| 4.2.2 | High potential of SDE to foster educational innovation | 174 |
| 4.2.3 | Strategy to foster sustainable awareness | 180 |
| 4.2.4 | Perception of the educational potential by the key SDE stakeholders | 93 |
| **4.3** | **Fostering skills for committed workforce profiles** | **199** |
| 4.3.1 | Enhancing professional capabilities through SDE | 201 |
| 4.3.2 | Empowerment synergies from industrial participation | 206 |
| 4.3.3 | Improving workforce & practical job skills | 208 |
| 4.3.4 | Leveraged SDE opportunities | 211 |
| **4.4** | **Benefiting from second life of SDE houses after the Competition** | **213** |
| 4.4.1 | Post-Competition uses of SDE houses | 213 |
| 4.4.2 | Successful educational outreach | 217 |
| 4.4.3 | Other rewarding university experiences with SDE houses | 223 |
| 4.4.4 | Exploiting solar houses in their second life | 225 |
| **4.5** | **Conclusions and lessons learned to improve education & training capabilities of SDE Competitions** | **227** |
| 4.5.1 | Related to SDE educational potentials | 227 |
| 4.5.2 | Concerning the fostering of workers' skills | 230 |
| 4.5.3 | In relation to post-Competition & living labs opportunities | 232 |
| 4.5.4 | Final conclusions | 232 |

# introduction

**Since the very beginning, the Solar Decathlon has focused on the education of young university students and the training and education of the next generation of architects and engineers who will have the responsibility of establishing a more efficient and sustainable society. When the Competition came to Europe as a result of the MOU signed between the Spanish and American governments in 2007, the spirit of the Competition was maintained, and its focus was on the education and development of skills, and the professional training of European university students, to approach the demands of a society that wants and needs to be sustainable, and zero carbon emissions.**

When the first edition of the Solar Decathlon Europe was launched in 2010, in addition to the focus on university education, the objectives were expanded in a double sense:

1. To generate knowledge on the industrialization and sustainability of the houses, dissemination of the knowledge, and its transfer to professionals and industry.
2. To take advantage of social interest and high media impact to make students, professionals and the general public aware of environmental and sustainability issues, especially in the responsible use of energy and natural resources, promoting the use of the renewable energies, improving energy efficiency, etc.

This meant, in fact, broadening the focus of education and social awareness to both future generations (children and young students) and present generations (both professionals and citizens in general). In following editions of Solar Decathlon Europe, the spirit and focus on the education of university students and their preparation for the demands of the market has been maintained, extending social awareness to the main sectors of our society, and in particular to children, young people, professionals and the general public.

To what extent have we been able to take advantage of the synergy and educational potential offered by the Solar Decathlon Europe Competitions? What perceptions do university students have of the educational enrichment that their participation in the Competition has given them? To what extent have we been able to promote transversal skills in our students? To what extent have we been able to raise awareness among young professionals and citizens? Do we take advantage of the educational and research potential that the houses have after the Competition? All these questions require a careful analysis, constructive conclusions and lessons learned to improve the use of the synergies that Competitions generate.

solar decathlon europe

The objective of this 'Technical Report 4: Education and workforce enhancements' is to provide an insight, through surveys and interviews, into the real impact of the Solar Decathlon Europe Competitions, both from the educational and professional training point of view, as well as from a social and professional awareness perspective to make buildings and cities more energy-efficient and sustainable. It should be noted that the results of the surveys have been interpreted in an overall manner, evaluating the joint impact or the different editions of Solar Decathlon, without wanting to discern which have had a better or worse performance from the point of view of education and professional training. It is not the aim of this report to compare some Competitions with others but to evaluate the overall experience.

To this end, this report is divided into four chapters that critically analyse the surveys and interviews carried out so far on the Solar Decathlon Competitions, the educational and social awareness balance, the development of skills appreciated in professional work, the educational and research potential of the post-Competition use of the Solar Decathlon Europe houses and the conclusions and lessons learned from the critical analysis of these assessments.

solar decathlon europe

# 4.1 sd surveys and participatory research

### 4.1.1 Surveys in SD. Description

Surveys have been conducted in the Solar Decathlon, with different approaches, they tackle the educational impact of the Solar Decathlon but not at the same depth. Table 4.1. brings together the main surveys carried out for the purposes of this Report, defining the scope, authors, target groups, number of participants, etc.

**Table 4.1: Solar Decathlon Surveys**

| Competition | Solar Decathlon USA carried out by a specialized company | | |
|---|---|---|---|
| Target groups | Homeowners, former Decathletes, non-Decathletes, former students | | |
| Event time | 2002,2005,2007,2009 | | |
| Total in survey | 1 164 answers | Unaware homeowners | 400 |
| Visitor homeowners | 200 | Total former Decathletes | 174 |
| Aware homeowners | 280 | Total non-Decathletes, former students | 110 |

| Competition | Solar Decathlon Europe 2012 carried out by the organisers | | |
|---|---|---|---|
| Target groups | SDE12 Teams and students. | | |
| Event time | 2012 | | |
| Total non-professors | 19/8 | Non-Students | 313 |

| Competition | Solar Decathlon Europe 2014 carried out by the organisers of a workshop developed during the Competition | | |
|---|---|---|---|
| Target Groups | Present and past Decathletes, organisers, and professors. | | |
| Event Time | Worldwide survey | | |
| Total Non-Student | 151 sent, 60 full answered | Total non-professors | 85 sent, 39 full answered |

| Competition | SD Worldwide survey designed and carried out by UPM |
|---|---|
| Target groups | Present and past Decathletes, organisers, professors, citizens, institutions, professionals, and companies. |
| Event Time | Worldwide survey |
| Year | 2020 |
| Total non-professors | 340 (until September) |

These Surveys (or a part of them) in which a specific educational approach was taken are described with the objective of reaching common overall conclusions. It is extremely important to conduct surveys / interviews on the Competitions so that, it would be possible to have the feedback of the main stakeholders from the different Competitions for its overall analysis on the effectiveness of this event and to generate indicators that allow, in addition to assessing the impact of the Competition, improvements to be obtained to optimize the investment of a major event.

solar
decathlon
europe

### SDUS12 SURVEY

The Solar Decathlon 2012 Impact Evolution Survey was submitted to the U.S. Department of Energy with the aim of evaluating the US editions from 2002 to 2011 and the main objectives of the Competition. The survey also aimed to assess the contribution of SD in the United States and the role that Competition played in the lives of post-Competition Decathletes.
Furthermore, it was possible to improve the following editions because of the recommendations made by the participants of the first four editions.

The Solar Decathlon 2012 impact evaluation survey was carried out in three ways.
Homeowner telephone, former Decathlete online questionnaire and non-Decathlete, former-student telephone questionnaires. The main outputs are suggestions and improvement for future editions of the SD, post-Competition feedback and the benefits gained from the Competition for students, professors, schools, cities, organisers, etc.

### SDE12 SURVEY

The objective of this survey was to collect specific data from Decathletes and Teams in order to draw up a general estimation on the perceived performance of SDE12 Competition and to have statistical data on the Teams and students participating. Simple questions related to number of participants, degree of study, gender information, qualification of professors, etc. The survey for the Decathletes is made up of an assessment of the participating students in relation to the Competition within the scope of Rules, organisation, communication, experience, etc.

### SDE14 SURVEY

The main objective of SDE14 Survey was to provide feedback on the experience of professors and students with the SD to be analysed and discussed at the Workshop on the Solar Decathlon Europe Educational and Research Approach, in which how to share experiences from different universities in harnessing SDE to make students aware of energy-efficiency and the improvement in sustainable conditions in our buildings and cities was discussed.
A general survey was sent to the Decathletes, organisers, and professors, to learn about their experience, and to collate information on three different topics:

- **Team launching & development:** Institutional support, Team members, organisation, etc
- **Educational approach:** Strategic frame, specific courses, knowledge, and experience acquired, etc
- **Research results:** Strategic frames, PhDs. Theses, patents, innovation, etc

### 4.1.2 Surveys about education in SD: description

The impact assessment of the SD Competitions in the lives of the students is one of the main aspects when carrying out these surveys. The knowledge and experience acquired and stimulated during their participation in the SD Competitions should serve the former students in an easier incorporation into the job market.

solar decathlon europe

For instance, in the educational field and the impact on the labour market with the SDUS12 Survey, it was possible to obtain answers on aspects such as the knowledge and experience gained by former students on cost-saving opportunities, construction features, purchase prices, applications of solar energy, and use of energy-efficient products in houses with solar energy systems. This survey also aimed to find out the percentage of former students at the following points: Those who found a job in the clean-energy workforce and the influence of the Solar Decathlon on the job seeking of former Decathletes; those who found employment in the clean-energy workforce; the percentage of alumni who started a clean-energy business; the influence of Solar Decathlon on the success of ex-Decathletes in encouraging solar energy installations and efficient equipment.

According to the results presented at the SDUS12 Survey, 92% of ex-Decathletes claimed that their experience with solar decathlon helped them to get jobs. It was also found that five times more ex-Decathletes worked in the field of clean energy after leaving college than non-Decathlete students (76% and 15% respectively). The data from this survey is very important because it states that the main objectives of the Competition were achieved.

In the SDE12 survey, the Decathletes who were competing in that edition were asked questions, while the 2014 survey was oriented to former SD students and professors worldwide. In both cases, the main objective was a little different from the North American survey and focused more on education and capabilities gained through the SD Competition. It was to establish the impact of SD during the Competition in a context of skills and knowledge developed by the students throughout the process. The options that had the most responses were communication, public relations, project management, scheduling, productivity, teamwork, construction, and leadership. Students also said that the main knowledge developed during their participation in the Competition were: architecture, engineering, integrated design, construction, and materials. The vast majority do not regret having participated and would probably participate in a following edition. Below are the graphs with the information generated by the survey in an educational context:

The results of the surveys show the importance of the opinion of former Decathletes to continue in the following editions and how these results can influence the development and organisation of the Competition.

### 4.1.3 SDUS20 Survey: description

#### 4.1.3.1 SDUS20 worldwide survey

The main objective of the SDUS20 survey is to reach people who have had some direct relationship with any of the editions of Solar Decathlon worldwide to date, in order to gather relevant information on their feedback, perceptions, experiences, etc, to assess the impact of the Solar Decathlon in very different topics, education and training among others, to create a plan of what can be done to improve future editions.

solar
decathlon
europe

The survey is aimed at people who have previously participated in an edition of SD, either as a student, or as a professor, institutions, organisers, companies/professionals in the field, or citizens. It was first launched on a preliminary basis in the SDE19 edition in Szentendre, Hungary, and is currently still collecting responses.

The survey is available on the Internet, allowing people to respond no matter where in the world they are. There are several types of questions: multiple choices, yes/no, open questions, assess and select options. The survey is divided into three parts. The first one focuses on general questions, being equal for everyone. The answers allow the user from an overview to make a classification. The second part is the most extensive and is aimed at each group. There are five targets groups: students, institutions and professors, organisers, industry and professionals and citizens. In this part, questions are asked which were aimed at finding out what was developed and used in the Competition. The last part includes open questions to establish the opinion of users and their suggestions about what could be implemented to improve in the Competition.

The main output of this survey is to use the answers to learn about the real impact of Solar Decathlon on many different topics and about suggested actions to improve future editions so that the event will be used in the best way from an economic, technological, and educational and awareness standpoints.

#### 4.1.4 Interviews

For the drawing up of this report, together with the 2020 surveys, semi-structured interviews have been carried out with the main objective of obtaining in-depth suggestions for improvements and feedback from the Competitions held. It is another tool to use in favour of the improvement and progress of the Solar Decathlon.

##### 4.1.4.1 SDME18 interviews (during Solar Decathlon Middle East Competition)

The objective is to obtain the opinion of the Teams regarding their participation, development and learning in the Competition. 80% Of the participating Teams were interviewed and the interview was divided into three parts. One of general questions, another of documentation and scientific relevance and finally Competition concept.

The SDME18 Survey is very didactic, and it was designed for Teams to score the questions asked. Among the questions, the Teams had to rate the challenges of the Competition, what could be done to improve the Rules, the contests, the organisation of the event, the visitors, about the professionals, about the houses and everything involved in them. It allowed the great challenges and problems faced by the Teams to the evaluated, suggestions for improvements for future events, and the post Competition in the life of the Decathletes.

solar
decathlon
europe

#### 4.1.4.2 SDE19 interviews with students and faculty advisors

The objective is to benefit from the Solar Decathlon Europe 2019 to obtain information on the setup of the event. A student and a teacher from each Team were personally interviewed during the Competition to find out the quality of the event and what could be done to improve future European editions.

The survey is divided into seven parts: general questions, specific questions about participation, about the university, about the Competition, specific about the event and organisation, market, and finally open questions. The main objective of this survey is to gather information necessary to generate improvements for future European editions.

#### 4.1.4.3 SDE 2020 interviews to faculty advisors and professors of SDE10, SDE12, SDE14 and SDE19

The objective is to obtain direct feedback from faculty advisors and professors mainly about the post-Competition use of the houses and the key drivers to improve future Competitions. A qualitative analysis regarding the educational balance of the Solar Decathlon Europe and the post-Competition use of the Solar Decathlon Europe is carried out via questionnaires sent to faculty advisors. To find out the present use of the houses and how many of them are still in use and to obtain proposals on the key drivers to prioritize action in the development of future Competitions.

#### 4.1.4.4 SDE10 and SDE12 Industry and professionals' interviews

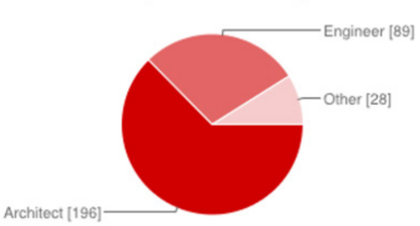
The objective is to obtain direct feedback from a different point of view than just the academic. In February 2020, a conversation with the sponsors and professional involved in the Solar Decathlon Europe 2010 and Solar Decathlon Europe 2012 took place. The questions were directly related to the objectives of this report. The general output was significantly positive. However, the general opinion that the impact of SDE in the market could have been much greater was remarkable.

### 4.1.5 General information on the profile of the respondents

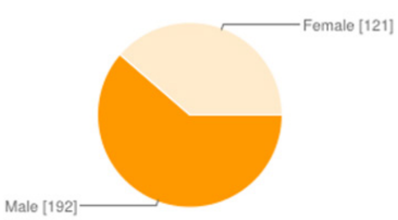
The output from the surveys and interviews will be the basis for establishing how the Solar Decathlon has impacted on students, professors, organisers, citizens, professionals, etc. With these indicators, it will be possible to develop and reach conclusions on how to improve and optimize the Solar Decathlon Competition. The analysis in this report has been mainly based on the results of the survey conducted in 2020 specifically for this report (in conjunction with the ongoing study at the IEA EBC Annex 74 of the Energy and Buildings Community programme of the International Energy Agency). The results of the SDE14 survey have been analysed in a complementary manner, as well as those of the SDE12 survey. No results from the DOE survey in the USA have been used.

solar
decathlon
europe

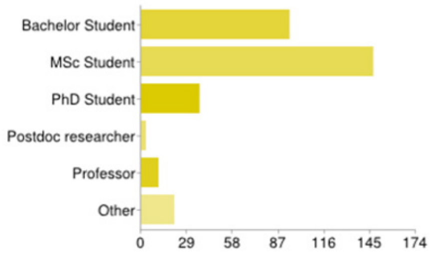
Professional/student backgournd



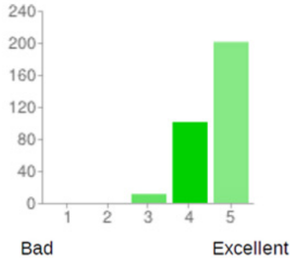

Gender




Professional/student status




SDE12 Overall experience




Would you recommend other students

to participate in future Solar Decathlon editions?

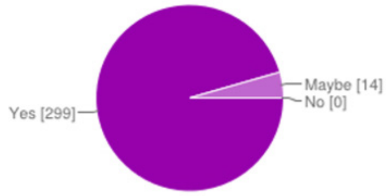
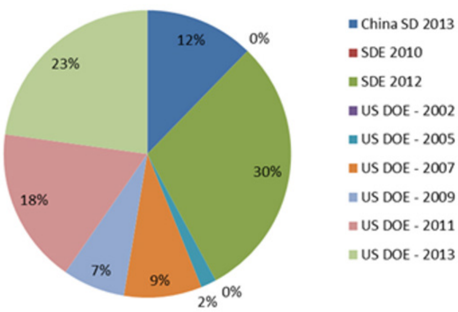


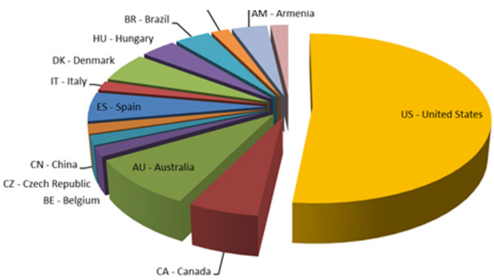

Figure 4.1: SDE12 Survey.

Profile of the surveyers.

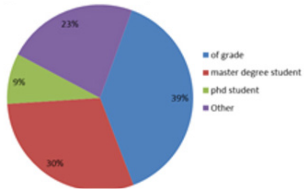
Which competition did you participate in?




With which country did you participate?




Student during the competition




Student after the competition

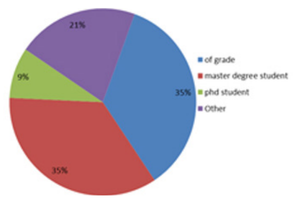



Figure 4.2: SDE14 Survey.

Profile of the surveyers.

solar
decathlon
europe

In the survey conducted for the 2012 Competition, students and professors from all participating Teams took part, with a total of 313 respondents. The majority were students of architecture and engineering, and most were master's degree and PhD students, and to a lesser extent undergraduate students.

The survey carried out in 2014 was designed to be answered by two target groups: students and professors, with similar questions to allow for a comparative analysis. 151 students responded to the survey with just over half of them coming from the United States, contacted through the alumni association. 30% were former SDE12 Decathletes. 39% were under-graduate students, 30% were master's degree students, and 9% were PhD students. Almost 5% of the total later became master's degree students, most of them having been undergraduates.

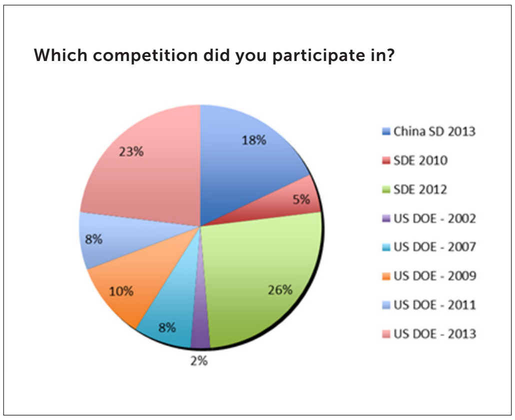
The survey of academics was answered by 85 professors, mostly from the United States, and with most respondents participating in the SDE12 and SD13 Competitions in the USA.

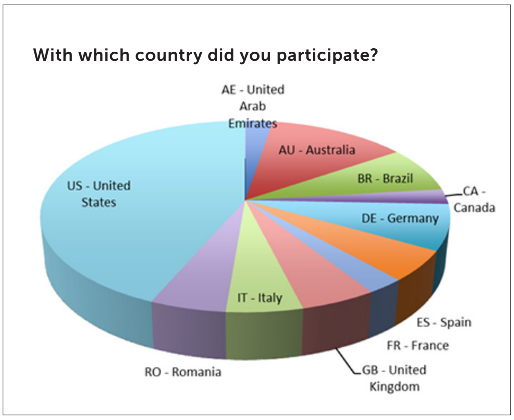
As regards the survey conducted in 2020, by the end of April 2020, 316 responses were gathered among students, institutions and professors, organisations, professionals, companies, and citizens. Throughout this report, the relevant results of the surveys and interviews carried out will be presented. In general terms, the level of satisfaction with the experience is very high. In the SD worldwide survey 87% of the survey respondents would participate again, and 97% would recommend taking part in the Solar Decathlon.

Most of the answers are from the latest Competitions, participants from all the Competitions the world over answered the survey (Figure 4.4). 55.55% of the answers came from students, (26% MSc students, 21.27% BSc students, and 8.25% PhD Students) 19.37% from professors, 7.94% from professionals and 8.89% from the organisers. Other respondents came from institutions, companies, and citizens.

Figure 4.3: SDE14 Survey.

Profile of the Professors Surveyors.



solar
decathlon
europe

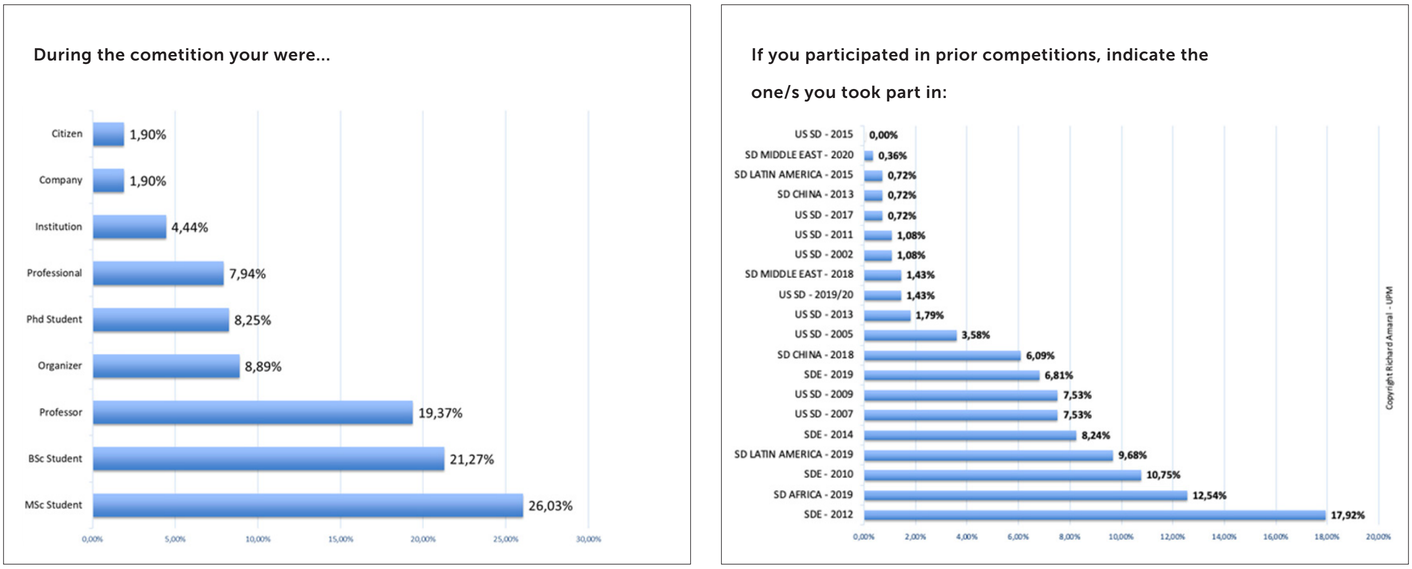
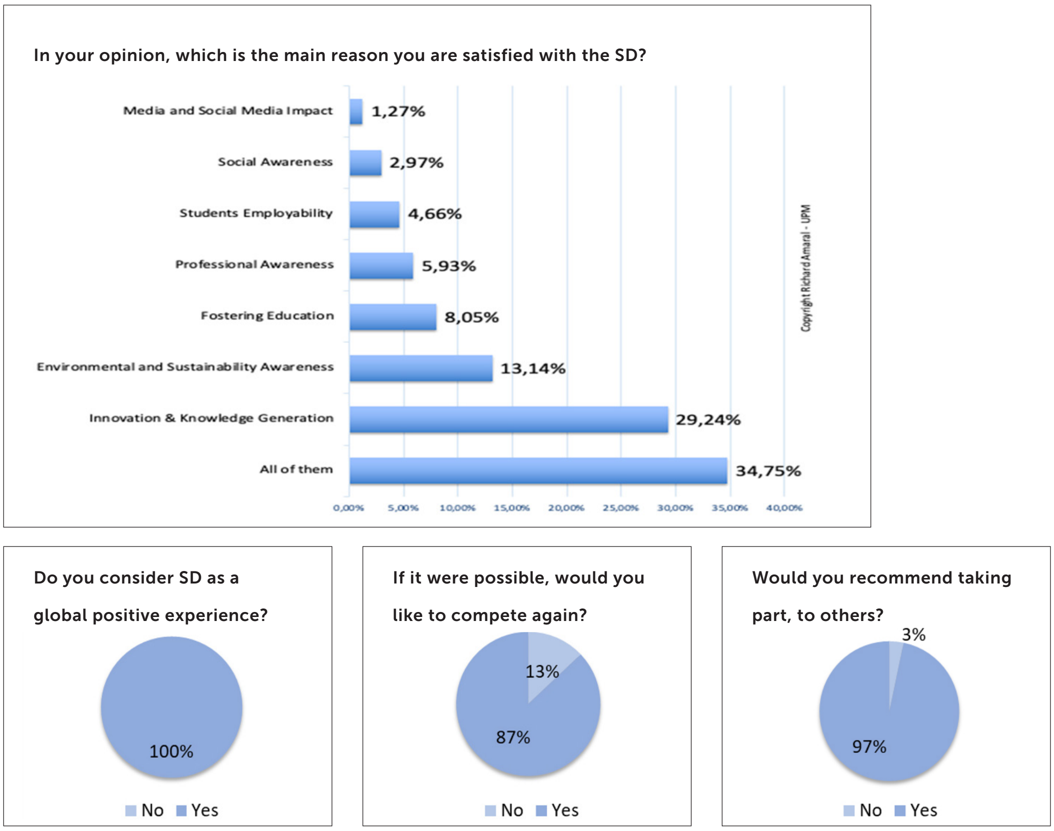



Figure 4.4: SDE20 Survey.
Profile of the Surveyors.

100% of survey respondents consider the Solar Decathlon and overall positive experience, and when are asked to choose the reason they are satisfied from a list of items, 35% answered ‘all of them’, followed by 29.75% ‘innovation and knowledge generation’. When asked if it were possible, they would like to compete again, 87% answered yes, and if they would recommend taking part to others, 97% answered yes.

Figure 4.5: SDE20 Survey.
Satisfaction of the Surveyors.



solar
decathlon
europe

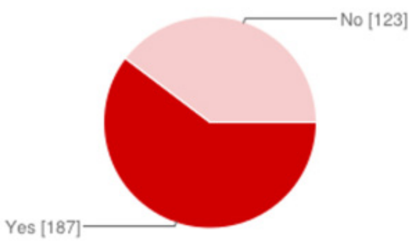
## 4.2 sde educational balance

### 4.2.1 SDE underlying objective: education of university students

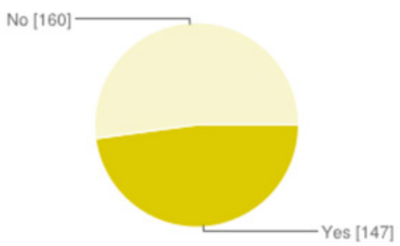
Just as the Solar Decathlon Competition since its first edition in 2002 organised by the DOE (US Department of energy) has always had education as one of its declared objectives, so the Competition in Europe has had as its permanent objective the education of university students and the preparation of a new generation of architects and engineers who are aware of and committed to the environment, and to making our buildings and cities more efficient and sustainable. When a university decides to participate in a Solar Decathlon Europe Competition, the university not only takes on the challenge of designing an efficient, zero-energy prototype home, powered exclusively by the sun, that is attractive, healthy, comfortable and convenient to use, but also assumes all the challenges associated with managing the project, making it technically, economically and financially viable, both in its construction and the challenge of assembling and dismantling it in the shortest possible time, competing in unfavourable situations and under pressure. Considering the money that the university invests to make the project viable, the economic and human effort involved, the possible difficulties derived from the Competition, all the risks involved, etc. Why do universities ask to participate in the Solar Decathlon Europe Competitions? Why are many of them reluctant to try to participate again and again?

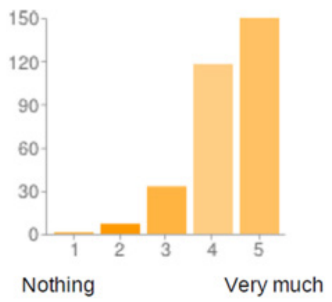
Figure 4.6: 2012 Survey.
Technical education.

Are you doing (or have you done) some research work related to the SDE?

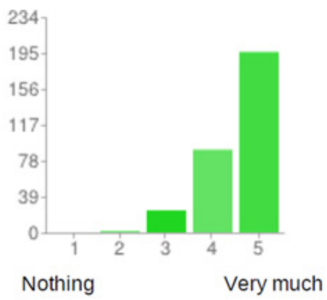



Is (or will be) your end-of-studies final project, or thesis, related to some of the issues of the SDE?

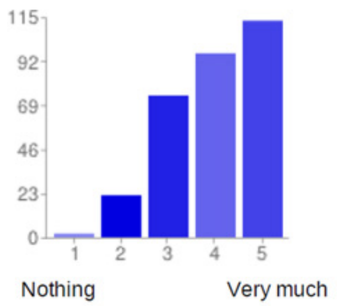



Has getting involved with the SDE helped you gain a better understanding of solar energy systems?




Has getting involved with the SDE helped you gain a better understanding of the construction process and the facilities in buildings?




Has getting involved with the SDE helped you gain a better understanding of home automation?

solar
decathlon
europe

There are many reasons that encourage universities to participate despite the challenges and risks associated with these Competitions, and without doubt, one of the most significant is the educational potential that participating in a Competition like the Solar Decathlon Europe represents for the university. The participation generates an endless number of educational synergies of all kinds, from the generation of technical knowledge and its application, to the development of transversal skills so necessary for the working life of the participants; from the integration of complementary disciplines from architecture or engineering, to the application of project management skills; both for the student Decathletes who participate in the Competition, to the schools that contribute to the professors and students and that can equally benefit from the educational potential of the project development; from learning and education during the development of the project, construction, and Competition, to the use of the house after the Competition that continues to be an excellent scenario that generates educational synergies and fosters research, innovation, social awareness, and knowledge transfer to professionals and industry.

Although the greatest educational potential derives from the Competition itself, and the design and construction of the prototypes, in order to maximize the benefits and synergies of this potential, an active commitment is needed from the universities and faculties that participate, as well as from the organisations of the Competitions and related events, which have the means to foster the educational focus of the work of the Teams, and to develop activities that promote the awareness and education of both the students and the visiting citizens in general.
Likewise, when a country, or a city, decides to take on the challenge of organising a Solar Decathlon Europe Competition, one of the many returns that it values is, no doubt, the potential for social and educational awareness that it represents for society. The communication potential of the Competition is very high, due to the attractiveness of the houses, the technical innovations they present, and the media interest they generate. This potential is therefore at the service of the awareness and education of children, young people, university students, professionals, and the public in general, one of the powerful reasons for taking on the organisation of one of these prestigious Competitions.

#### 4.2.1.1 Education coming from universities

The educational potential is very high, but there is no doubt that in order to take advantage of all the synergies, a willingness and planning of the university's teaching and educational activity is needed to enable it to be used, which, judging by the assessment of students and professors in the 2020 survey, is not always achieved. For example, when asked if Solar Decathlon is part of the university's training program and if credits are recognized for participating in the Team, only 38% of students agreed, and the degree of agreement among professors is 3.5 out of 6, with a very high dispersion (1 in total disagreement, 6 completely agree).

Similar results were achieved in the survey of Solar Decathlon Europe 2014, with a lower evaluation by students than professors.

solar
decathlon
europe

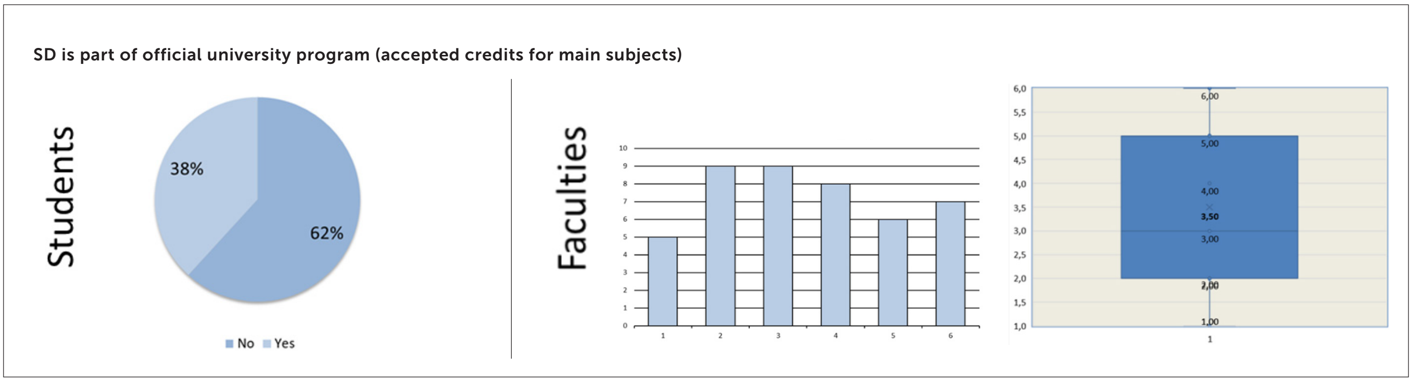



Figure 4.7: 2020 Survey.

If we analyse the result of the survey during the SDE14 Competition, on whether the professors focused on the Competition in which they participated as learning activities, the average value would be 3.11 out of 5 for student perception, that is, it is recognised that it was generally tried, but it is not clear that it was achieved. However, for the professors, although the average value is 3.26 out of 5, which is similar to the overall perception of the students, it contrasts with the fact that 37% of the professors surveyed considered the statement to be completely true, as opposed to less than half of the students with this perception.

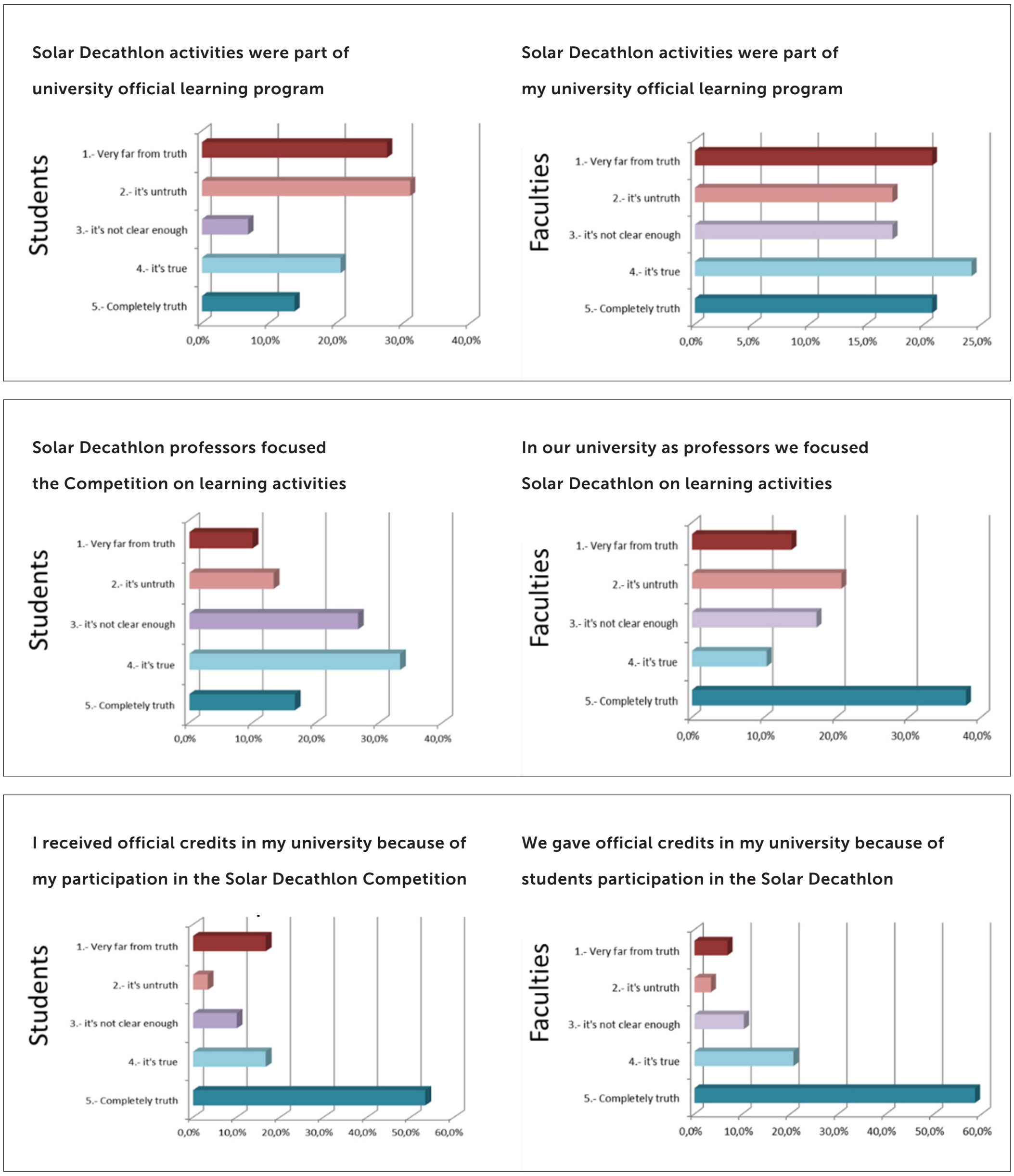
It can be seen from the SDE14 survey that in most of the participating universities, official credit was given to students who participated in the Solar Decathlon Competition, which is an explicit recognition of their educational and professional training potential.

This recognition of students by universities does not equally translate into recognition of their professors. In the 2020 survey, it is meaningful that universities do not always recognize the work and effort made by their professors to develop the project, it not having affected their working conditions in a significant way. The average response value was 3.65 out of 6, with a very high dispersion, which implies a great variety of responses depending on the universities to which they belong. Some of them recognize more, many others do not recognize this activity at all.

Asked by the professors if the budget they considered for the Competition was sufficient to promote academic activities, the answer once again is an average value of 3.11 out of 6, with a somewhat lower dispersion than the previous cases, and which we interpret as meaning that there has not been clear support from the universities to promote specific educational activities within the university.

solar
decathlon
europe

Figure 4.8: 2014 Survey.



solar
decathlon
europe

Figure 4.9: 2020 Survey.

Has the university recognised the work you did at SD in your performance review / labour conditions?

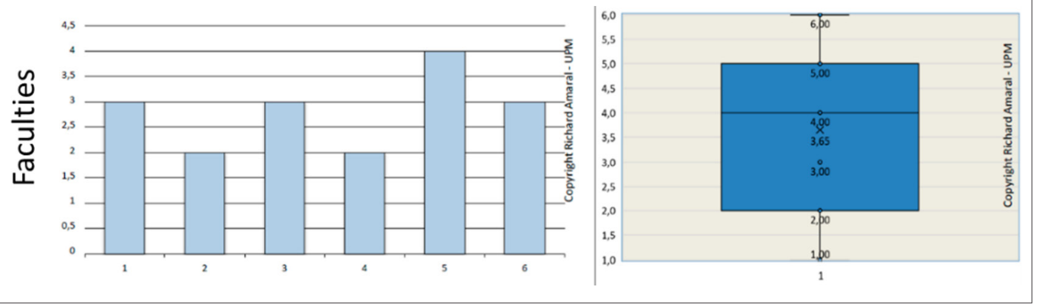
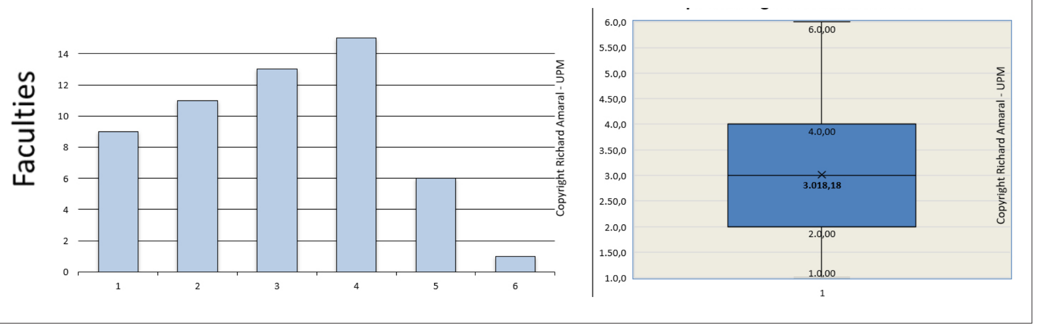



Figure 4.10: 2020 Survey.

Budget for participating in SD was enoughfor promoting academic activities




4.2.1.2 Education fostered by the Competition itself and its organisation

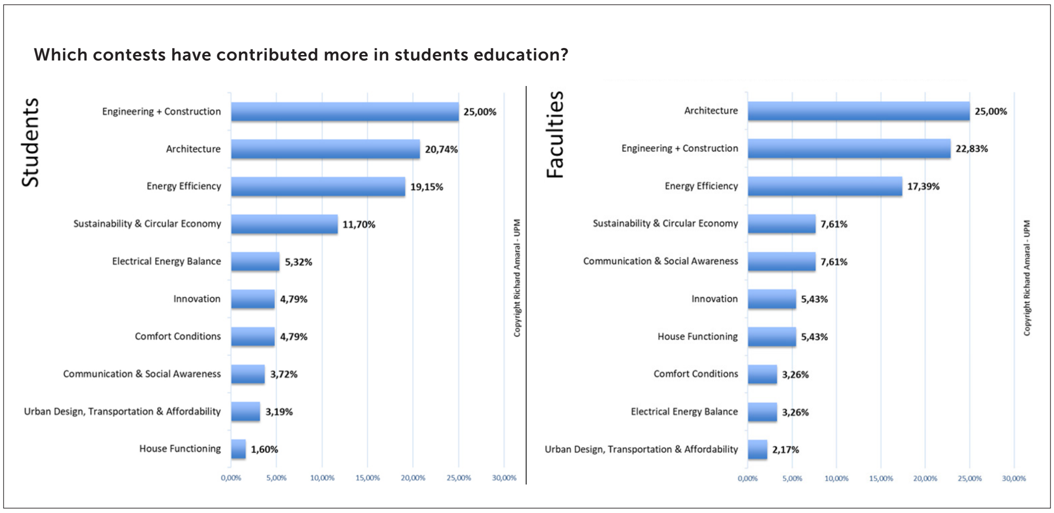
Beyond the educational approach that each university has given to the Teams participating in the successive editions of Solar Decathlon, which as we have seen is diverse and the subjective perception of it is discussed, the greatest educational potential lies in the Competition itself and its contests, in addition to all the activities linked to the events around the Competitions.

As regards the Competition contests, there was a significant variation in the contests with respect to the American editions when the Competition moved to Europe, among other things to adapt them to European sensitivities and values, and on the other hand to promote social awareness and education in important and sensitive aspects in Europe. Subsequently, several of the European contests were incorporated into subsequent American editions, in a mutual process of continuous improvement.

Therefore, to the engineering contest was added the part related to construction, to communications was added the part of social awareness, and to the market viability contest points were added for industrialization, which later varied by incorporating aspects of urban design, urban mobility, affordability, etc. Completely new contests were added, such as energy efficiency, sustainability, or innovation. In total almost half of the points were adapted to the European edition between the SD2009 in Washington and SDE10 in Madrid.

solar
decathlon
europe

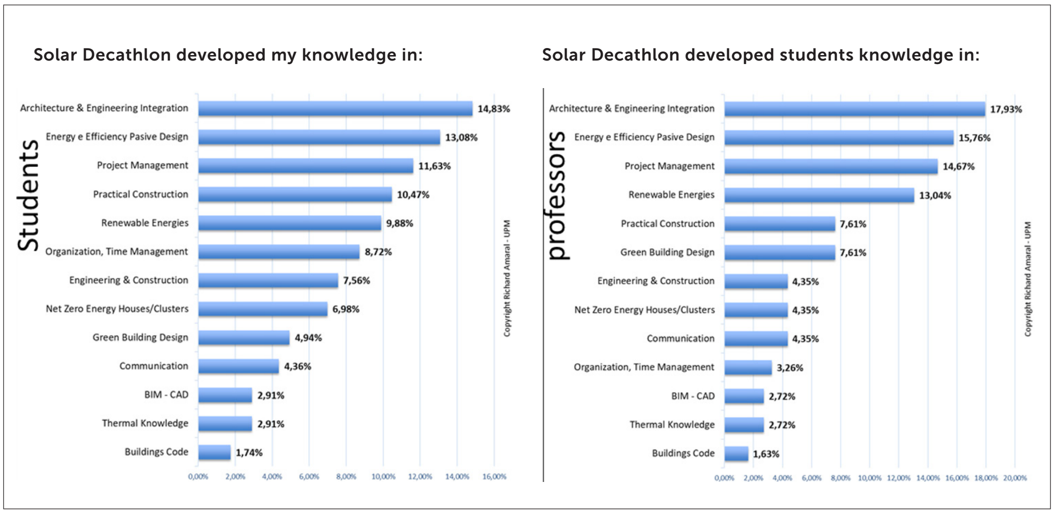
Figure 4.11: 2020 Survey.




The high level of coincidence in the perception between students and professors as to which of the contests in the European Competitions have contributed more to the education of the students is significant. The four contests that have contributed most (respondents had to choose only two out of ten contests) are architecture, engineering and construction, energy efficiency and sustainability & circular economy.

Also significant is the high level of agreement between students and professors as to what has improved the students' knowledge due to their participation in a Solar Decathlon Competition. Knowledge improved mainly in the following areas: architecture & engineering integration; energy efficiency and passive design; project management; renewable energies, and practical construction.

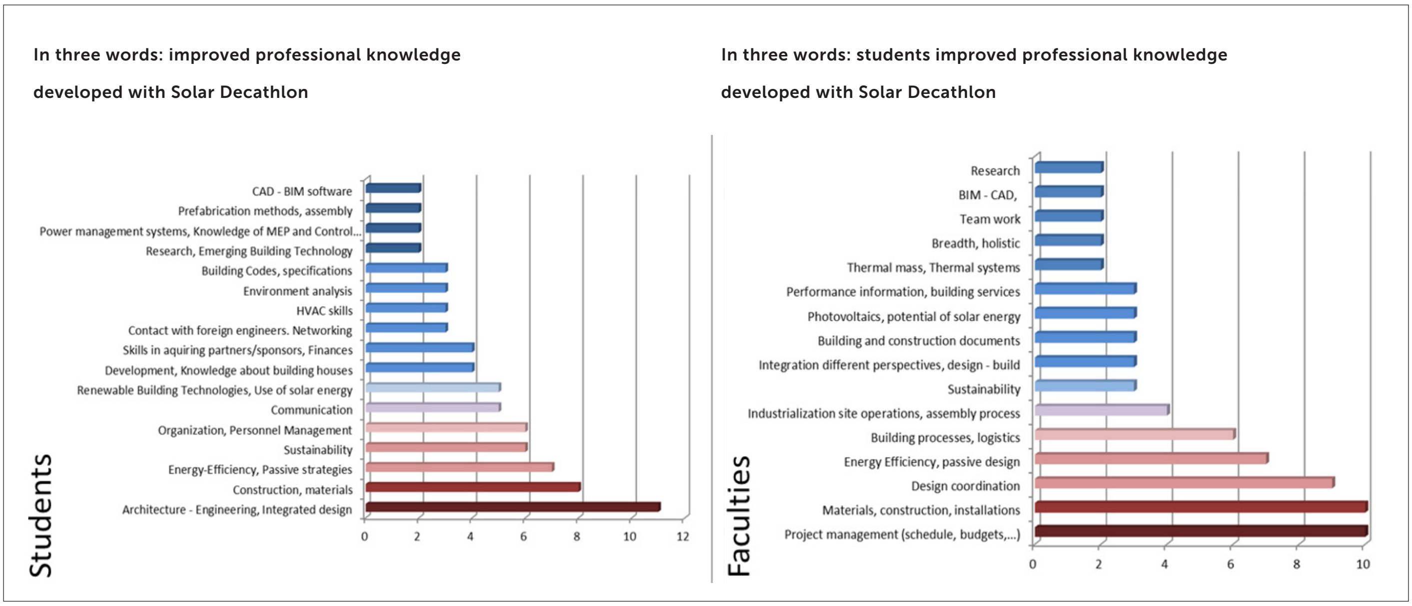
Figure 4.12: 2020 Survey.



solar
decathlon
europe

In the survey carried out in the SDE14, with an open approach in which 3 words were freely selected by the respondents, the dispersion of concepts was necessarily greater. While students valued learning about architecture and engineering Integration, construction, materials, energy efficiency and passive design, sustainability, or organisation and people management; professors highlighted knowledge in subjects such as project management, construction, installations, design coordination, or energy efficiency and passive design.

Figure 4.13: 2014 Survey.




From the organisation there is also a great capacity to influence issues related to education, personal skills development, and awareness in university students. For example, at the Madrid workshop in October 2011 corresponding to the SDE12 Competition held in Madrid, various activities and Team dynamics were developed to promote team building, the education of Decathletes, and the development of personal communication and leadership skills, etc.

Figure 4.14: Workshop SDE12 held In Madrid, October 2011.

solar
decathlon
europe


Figure 4.15: Material from Workshop SDE12 held In Madrid, October 2011.

Some of the materials generated by students are relevant to their perception of SDE and the values they transmit. Another example illustrating the influence of organisers in the SDE education performance are the Rules & regulations of every edition. For Instance, there will be changes regarding education in the Rules of next SDE21 in Wuppertal with the intention of stimulating the educational impact on the participating universities through the requesting of a new report to the Teams about, among others *"how is the participation in the Solar Decathlon (Europe) or comparable Competitions strategically integrated into the curricula and the broader strategy of the university?, How are the Teams' SDE21 concept and corresponding urban transformation topics integrated into research and teaching?; strategic planning on different levels (bachelors / masters / PhD / research / strengthening of connections and cooperation with other schools / field/fields of expertise / companies/ authorities; and operative planning of measures on different levels (projects, publications, courses, field trips, scientific dissemination of results; implementation, assessment / controlling."*

As regards the promotion of the educational aspects of the Competition from the organisation, it is widely documented and recognized by the faculty advisors of the Teams, as well as by the media, governments, and other public and private institutions. For example, after the 2010 Competition, all faculty advisors, on their own initiative and outside the organisation, signed a public letter called the Solar Decathlon Europe proclamation. The letter clearly stated the educational potential of Solar Decathlon Europe for university students, professionals and the general public. As regards the promotion of the educational aspects of the Competition from the organisation, it is widely documented and recognized by the faculty advisors of the Teams, as well as by the media, governments, and other public and private institutions.

In the letter addressed by the US Solar Decathlon Director (Department of Energy of USA), Mr. Richard King, to the General Director of Energy of the European Commission, Mr. Philip Lowe, to recommend that the European Commission provide support for the Solar Decathlon Europe. Mr. King stated, among other things that *"The inaugural event in Madrid last year proved how beneficial the Competition is. Hundreds of students and university faculty praised the event's educational value. The 200 000 people who visited the houses to see the sustainable designs were equally impressed."* (March 31, 2011)

solar
decathlon
europe

**Solar Decathlon Europe Proclamation**

We, the faculty advisors of the 17 university teams participating in the first Solar Decathlon Europe, make the following proclamation on 27 June 2010:

1. Solar Decathlon Europe has exceeded expectations as a learning experience for students from all over the world, providing the interdisciplinary educational opportunity of a lifetime and international exchange
2. Solar Decathlon Europe has exceeded expectations as a public demonstration and educational showcase for building designers & industry as well as the general public
3. Solar Decathlon Europe has successfully advanced the development of sustainable architecture and Zero Energy Buildings

Therefore, we have the following recommendations for Solar Decathlon Europe:

1. The European Union has to provide support for future events, participating teams, the subsequent use of houses and wider dissemination of research
2. Increase educational outreach within Europe by holding the event in different European countries.
3. The event should be further developed towards a profile reflecting dense urban living, building renovation and life cycle cost – in order to fully satisfy human needs.

On behalf of the 17 participating universities of the 2010 event, we congratulate the organizers of Solar Decathlon Europe and the Spanish Ministry of Housing for an impressive and highly successful competition. Solar Decathlon Europe 2010 is just the start. We all are committed to make this event a real catalyst for change.

Figure 4.16

Figure 4.17

Figure 4.16: Proclamation declared by the faculty advisors.

Figure 4.17. Villa Solar. SDE 2010 Competition. Madrid.

Later on, in the letter that the United States Secretary of Energy, Mr. Steven Chu, addressed to the European Commissioner for Energy, Mr. Günther Oettinger, to support the proposal that the European Commission take an active role in the management of the Solar Decathlon Europe, Mr. Chu stated among other things that *"The event provides practical, hands-on training for student participants while raising public awareness of the opportunities presented by construction methods and technologies that are available today."* (October 25, 2011)

The support of the European Union and the United States for the joint commitment to Solar Decathlon Europe is demonstrated, for example, by the joint press release from the EU-U.S. Energy Council in Washington, 28 November 2011, which states, among many other points, that *"The EU and the U.S. intend to cooperate on continuing the Solar Decathlon Europe Competitions, transforming them into an initiative to foster sustainable economic development by creating markets on both sides of the Atlantic for integrating innovative technologies and renewable energy sources into new and refurbished low impact buildings."*

### 4.2.2 High potential of SDE to foster educational Innovation

The education promoted by SDE Competitions is not only limited to the acquisition of new knowledge, or to the integration of different disciplines such as architecture with structural, construction, or installation engineering, but it has a very high potential to promote educational innovation and integral education by developing personal experience, transversal skills, and professional training, all of them essential for the new generation of architects and engineers we need to make buildings and cities more efficient and sustainable.

solar decathlon europe

4.2.2.1 Educational innovation provided by SDE

Educational innovation could be defined as the systematic and planned incorporation of transformational practices, aimed at improving teaching and learning processes. It is usually associated with changes and improvements with respect to traditional training based exclusively on the transmission and learning of theoretical knowledge. Educational innovation is not a one-off activity without a dynamic process that helps students in experiential and collaborative learning, proving more effective than traditional teaching methods, and complementing the constantly necessary theoretical knowledge.

Reflecting on the innovative potential of SDE, it is true that educational innovation implies the will to innovate and a planning of how to implement it, supported by theory, and a continuous process of reflection and improvement. In this sense, due to the temporary nature of the Competition and the lack of reflection by universities and teaching bodies, the innovative potential of SDE has probably not been sufficiently exploited. However, no one disputes this innovative potential, which allows for the identification of qualities associated with many of the main trends that are now recognised as effective educational innovation.



Figure 4.18: SDE14 Competition in Versailles.

Figure 4.19: Winner SDE12. Ècole Nationale Supérieure de Grenoble.

Without being exhaustive, we are going to give a brief summary of some of these recognized trends in educational innovation, highlighting how SDE provides close values.

solar
decathlon
europe

Figure 4.20: Winner SDE 2014. Universitá Degli Studi de Roma TRE (Italy).

### GAMIFICATION

We could define it as the didactic strategy of application of dynamics, metaphors, components, mechanics and principles of the games, in order to increase the motivation of the student in his learning process, to reach specific goals and to exercise specific skills and abilities. Among the wide variety of games that could be included in this strategy is undoubtedly that of university Competitions.

SDE is an excellent example where the university Competition impacts on the teaching-learning process, achieving significant results in terms of the high motivation of students who, by playing, learn the practical application of the knowledge acquired, improving in turn many of the students' transversal skills, such as teamwork, creativity, reasoning and critical analysis, problem solving, tenacity, resilience, and the ability to make a living.

### CHALLENGE-BASED LEARNING AND DESIGN THINKING

Challenge-based learning consists of an active learning strategy in which students solve a relevant and real challenge linked to the environment as a Team, up to the dissemination of the achievements. The techniques of design thinking promote a dynamic and exploratory design method to generate innovative solutions.

SDE is also a good example of these educational innovation strategies, as it focuses the student's interest on resolving the design of a prototype of a zero energy house, with very high energy performance. The resolution of the challenge not only favours the necessary interdisciplinary collaboration, and integration of knowledge and techniques of all kinds (projects, models, inventions, creative innovations, communication techniques, marketing techniques, social awareness, etc.), but also the collaboration with professionals and industry, sharing with partners, sponsors, and collaborators the common challenge, promoting creative innovations and the application of new products and systems.

This strategy applied in SDE generates, and this has been confirmed by the results of the surveys carried out in 2014 and 2020, a high level of student satisfaction; it generates highly productive group dynamics; it improves applied and multidisciplinary knowledge linked to professional development. It promotes the integrated development of specific skills and transversal skills such as entrepreneurship, teamwork, leadership, organisation and planning, logical thinking, problem solving, analysis and synthesis, creativity, collaboration, empathy, learning through research, digital culture, innovation and critical thinking, and communication skills. It also has a high potential in scientific-technical subjects, and for creating links between academic and business activity.

solar
decathlon
europe

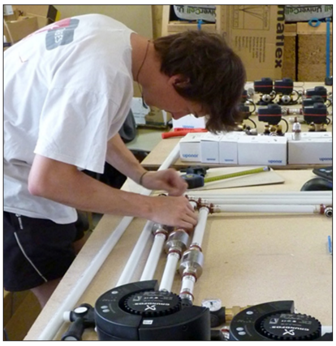


Figure 4.21: SDE14 Competition in Versailles.

### LEARNING BY DOING AND HANDS-ON EXPERIENCE

Learning by doing is an action-oriented methodology of educational innovation, and very close to the previously described methodology of challenge-based learning and design thinking. Ideas and concepts are still necessary but turning them into a tangible reality is a key factor for success. Learning by doing' is born with this spirit by putting the ideas designed by a Team of people into practice.

SDE is a good example of this trend in educational innovation. Learning derives from the application of studied knowledge and making it real in a tangible and authentic context, facilitating the resolution of problems of each Team in ordering the ideas to achieve the proposed objectives. The successes and mistakes are the basis of this methodology, which finds in experimentation a way to discover which elements work and which do not in each case. In this method, we aim for natural, team-based learning that supports their truthfulness in practice. Bringing ideas down from the conceptual world to the tangible world is key to achieving what a company needs.

Figure 4.22: German student In Madrid. SDE10 Competition.

The learning resulting from SDE derives from the stimulation of participation, activity, and materialism. It also encourages the sharing of ideas with colleagues, discovery through trial and error, and the development of basic competencies for the management of business resources, such as Team leadership, analysis and common problem-solving. Knowledge, skills and tools are obtained through action, joint reflection (students and professors) that leads to open minds and expand horizons, and experimentation (trial and error).

### SERVICE-LEARNING AND EXPERIENTIAL LEARNING

Experiential learning is the process of learning through reflection on experience. Experiential learning is a form of experiential education, but it does not necessarily involve students reflecting on their product, but on their experience gained. The methodology based on service-learning is collaborative and equally experiential, in which the student performs a service to the community, promoting critical analysis, understanding of social problems, and stimulating the proposal of solutions. The teachers who facilitate the process promote the students' protagonism from the design of the experience to the celebration of the achievements.

SDE promotes experiential learning in accordance with David A. Kolb's model. Not only do you learn by designing an energy-efficient and functional house, but you also learn a lot from observing the real performance of the house under real conditions, as well as interacting with the rest of the Teams in the Competition. The student learns from the analysis and reflection derived from the monitoring of the Competition, and from the objective score (by monitoring, or evaluation by juries of international experts) of each of the contests and sub contests, and from the general scoring. In order for experiential learning to be effective, the intention to learn is fundamental, and to this end students must be highly motivated, and be very proactive, conditions that SDE has been able to verify from the surveys carried out.

solar
decathlon
europe

Figure 4.23

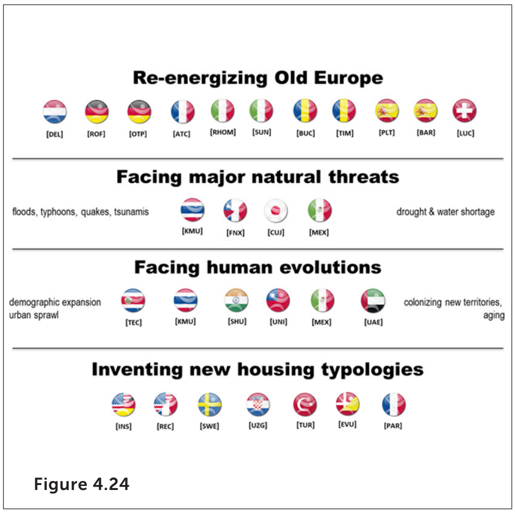



Figure 4.24

Figure 4.23: Université de Nantes. SDE14. Versailles.

Figure 4.24: Main changes faced in SDE14. (Pascal Rollet)

Experiential learning also extends to service-learning. In SDE, experiences have combined technical learning with the provision of services to the community, in various areas of social interest such as social awareness on issues related to the responsible use of natural resources, responsible use of energy, or what each citizen can do for a more sustainable and low-carbon world. The objective shared, for example, with the Teams of the SDE10 Competition, that each Team should take advantage of the house that they have built to raise awareness of all these issues related to sustainability, together with the strategy of the 10Action project, led to an interesting activity of social awareness that was part of the values won by the students in the Competition, resulting in a very rewarding experience for students, teachers, universities and the participating organisations themselves. SDE encourages the social commitment of university students and promotes the ethical dimension in academic training, strengthening the development of generic skills such as communication, teamwork, project management, social commitment, etc.

Another significant aspect is the challenge proposed by the organisation of SDE14 in Versailles to the participating Teams, that the houses proposed by the Teams should respond not only to the Competition's own requirements, but also to the social or technological challenges posed in their respective communities. This approach resulted in an enrichment of the Competition and a greater commitment of the students to respond to these challenges. Thus there were very suggestive proposals to respond to the great challenge of energy retrofitting in Europe, with proposals for zero energy industrialized units in existing buildings making the complete rehabilitation of the building feasible (Germany, Spain), or proposals to reuse and recycle existing buildings (Netherlands, Italy, Romania, France), or revitalize the sense of community by sharing spaces and infrastructures (Switzerland and Spain).

solar
decathlon
europe

Other equally interesting proposals tended to be oriented towards responding to natural hazards such as global warming and the consequent floods and typhoons (Thailand), human growth and urban agglomerations without the necessary infrastructure, with problems of drought and water scarcity (Mexico), or problems derived from seismic activity with earthquakes and tsunamis (Chile and Japan). Other challenges posed by the Teams attempted to bring together responses to human evolution with solutions to colonize new territories (UAE), of greater density to accommodate the expansion of the population in cities (India), or responses to the progressive aging of the population. (Costa Rica). Innovative solutions are also provided that reformulate housing in rows (USA, France, Taiwan, Italy), or in blocks (Sweden, Denmark, Spain, Turkey).

Figure 4.25: Team working in SDE14.

Figure 4.26. Ecole Nat. Sup. d'Architecture et de Paysage de Lille. SDE19.

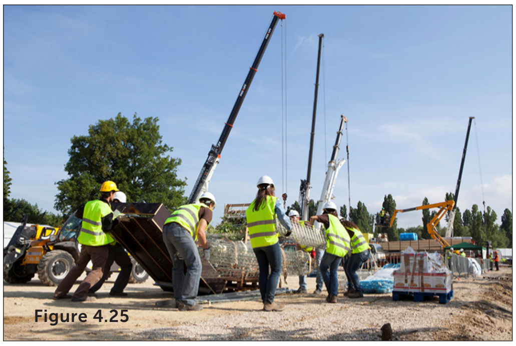


Figure 4.25


Figure 4.26

### LEARNING IN COLLABORATIVE ENVIRONMENTS AND TEAM-BUILDING EXPERIENCE

Learning in collaborative environments fosters collective intelligence by linking the potential of digital technology and the web, to encourage collaborative knowledge building. It is linked to ubiquitous, flexible, open learning, giving rise to processes that address enriched student experiences, as well as the personalization of experiences in knowledge communities and team-building experiences.

SDE is a Competition for multidisciplinary Teams of university students that, with the support of faculty advisors, have to give an overall and effective response to the multiple and varied requirements of the Competition, and only from the collaborative work of the Team, and from the construction of a solid and united Team, can it be done in a solvent way. The challenges posed favour both face-to-face and virtual collaborative dynamics, with a variety of tools such as team-building strategies (many Teams have come together through the association between two or more universities, in the same or different countries), collaborative repositories, agile collaborative tools, co-creation, co-development and co-construction techniques.

The interaction of SDE students in collaborative environments, and the use of social networks for formal and non-formal learning, have had a significant impact on the learning and development of transversal skills such as critical thinking, teamwork, intercultural and interdisciplinary competence, or internationalization.

solar decathlon europe

4.2.2.2 Comprehensive education

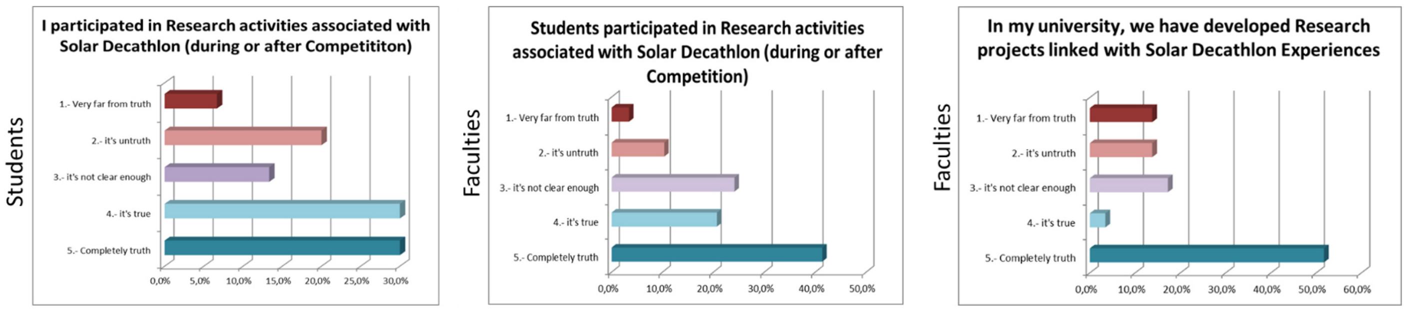
One of the most significant contributions of Solar Decathlon Europe from an educational point of view, is the comprehensive educational model it provides to university students, which includes not only the application of the theoretical and technical knowledge of the different disciplines it covers (architecture, engineering, communication, marketing, management, etc), often linked to innovation and research into new proposals, but also its practical hands-on application, as well as the professional training demanded by the labour market, the development of the technical, management and transversal skills necessary for their work as professionals, and the enrichment of personal experience by promoting active commitment to society. Without intending to be exhaustive, we are going to detail some of the approaches to these subjects.

### EDUCATION LINKED TO INNOVATION AND RESEARCH

The education promoted by SDE in many cases comes directly from the innovation and research developed within the framework of Solar Decathlon. For example, in the survey carried out at SDE14 to evaluate the participation of students in research activities associated with Solar Decathlon, 60% of both students and professors stated that they had participated in research activities during or after the development of the houses, which confirms the educational potential associated with innovation and research. And just slightly more than half of the professors surveyed said they had developed research projects linked to the Solar Decathlon experiences.

In the student survey conducted in 2020, 49% of the students stated that they had been able to do research during the development of the Competition, or had done research after the Competition, linked to the Solar Decathlon prototypes.

Figure 4.27: SDE14 Survey.




### HANDS-ON AND PROFESSIONAL TRAINING

The potential of SDE to promote hands-on learning and professional training and qualification is important and enriching. However, the SDE14 survey notes from both students and professors that universities did not plan professional training programs for Decathletes. 88% of students and 53% of professors stated that there were no such programs.

solar
decathlon
europe

This data contrasts with the perception, especially of the professors, that during the development of the Competition, educational and professional training activities were planned and carried out, with an estimated average score of 3.32 points out of 5, but with 47% of professors declaring that they had organised them. In any case, the students' perception was lower, with an average of 2.73. In any case, it is clear from the analysis of the results that there have been universities that have programmed educational and professional training activities, and many others that have not taken advantage of this potential.

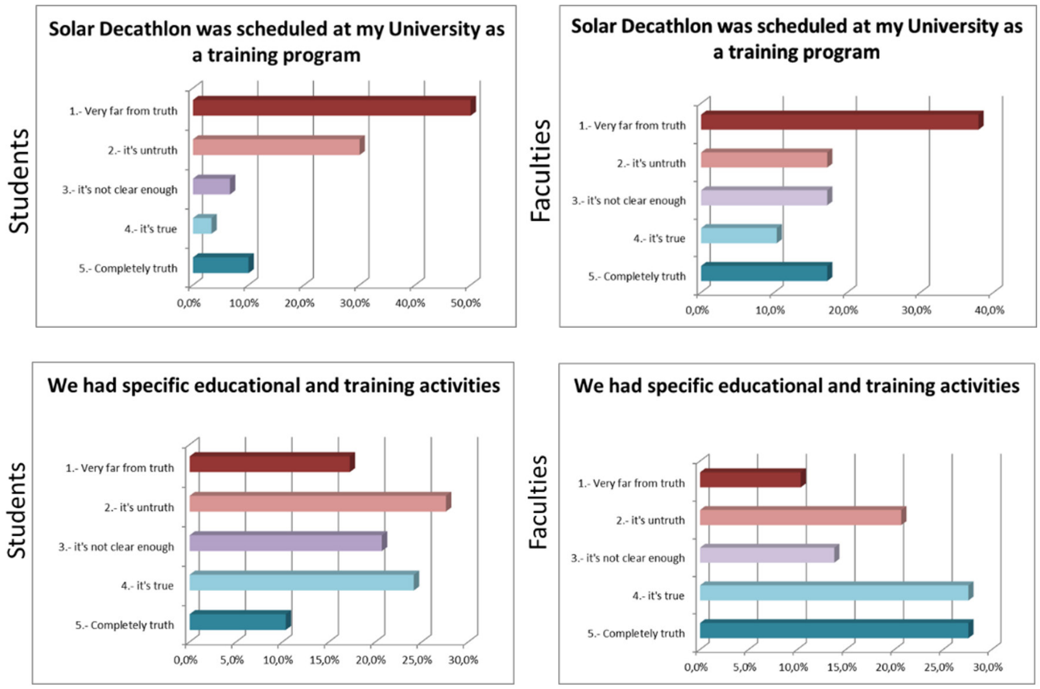



Figure 4.28: SDE14 Survey.

### PROFESSIONAL SKILLS DEVELOPMENT

Although not all universities have had a planned policy to promote education and professional development activities, it is very significant that there is great unanimity in considering that Solar Decathlon has contributed to the development of personal skills. Practically all professors, 97%, agreed or agreed strongly with this statement, with an average rating of 4.66 out of 5. This percentage drops to 81% in the case of students, with an average rating of 4.38 out of 5.

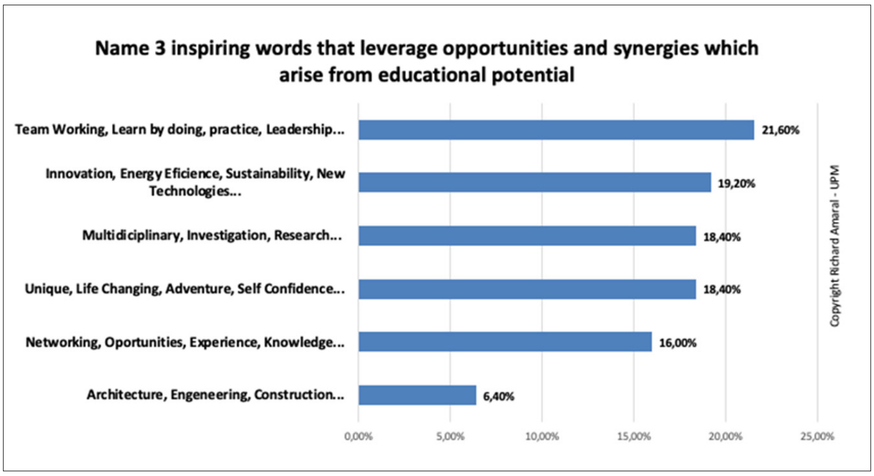
These data support the affirmation of the great potential that SDE has to develop personal skills which, as we will see in section 4.3 of this report with the 2020 survey, contributes to improve the employability of the Decathletes in the labour market. While students highlighted, in an open question in which they had to quote just three words, skills related to communication and public relations (17%), project management (16%), teamworking (11%), construction (9.5%) or leadership (6%); professors instead put in value the team building - collaboration (11%), project management (9.9%), construction with new materials (8.9%), design (8.9%), interdisciplinarity (7%), or communication (3.9%).

solar
decathlon
europe

### PERSONAL EXPERIENCE ENRICHMENT

Similar results, but with more points of agreement between professors and students are observed in an open question in which they had to quote just three words, related to Improved personal experience developed with Solar Decathlon. While students highlighted communication (10%), teamworking (7%), friendship (5.9 %), Contacts, networking (5.9%), or open minded and less insecure (5%). Professors put in value communication (11.9%), teamworking (9%), sharing with students (7.9%), friendship (6.9 %), hard working under stress conditions (5.9%), or cooperation and integration (3.9%). There is no doubt that Solar Decathlon enriched the personal experience of each of the students who participated in a Competition.

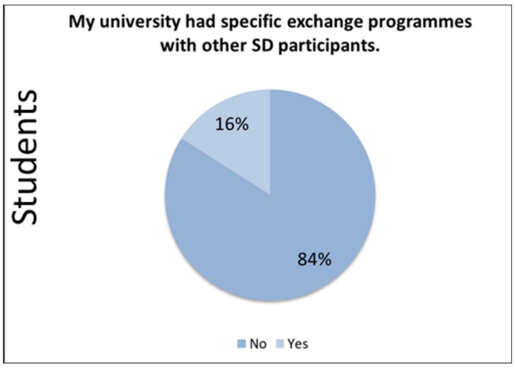
Figure 4.29: SDE14 Survey.




In the 2020 survey, to the open-ended question of naming three inspirational words that leverage opportunities and synergies which arise from SD educational potential, the most frequent were related to team working, learn by doing, practice, and Innovation, energy efficiency, sustainability etc…

Finally, it is worth highlighting that Solar Decathlon could encourage exchange programmes between students from different universities participating in the Competitions, but so far only small occasional operational exchanges have taken place for the coordination of mixed Teams, thus wasting a potential that could be enriching for university students. In the 2020 student survey, only 16% of students stated that their university had specific exchange programmes.

Figure 4.30: SDE14 Survey.



### 4.2.3 Strategy to foster sustainable awareness

Although Solar Decathlon has always focused on the education of young university students, and since the first editions in the United States encouraged the visit of the general public and the organisation of small demonstration spaces, it was not until the first edition in Europe with the SDE10 held in Madrid when it raised the specific objective for the European editions to take advantage of the media and social interest in the Competition to promote educational activities and social awareness for the public in General.

This strategy was reinforced by the development of the 10Action project financed by the European Union within its Intelligent Energy Programme, and by the strategy of sharing with the SDE10 Teams the objective of contributing to raising the awareness of European citizens in their city environments. As detailed in the Thematic Report 3, in large numbers, the final balance of Project 10Action has meant:

- 9 350 European children who have actively participated in the 10Action activities and games organised for them.
- 6 967 European teenagers who have participated in the debates and Competitions 10Actions organised for them in various countries.
- 2 086 university students from 12 European countries who have participated in the workshops, conferences, debates, and Competitions organised by 10Action.
- 43 854 professionals from the construction sector who have participated in the exhibitions and conferences organised throughout Europe.
- 42 803 European citizens who have participated in the model exhibitions, visits and demonstrations held in the various European countries involved.
- In total, 180 514 European citizens of all ages who have actively participated in 10Action activities, and have had the opportunity to reflect and learn about the responsible use of energy and how to contribute to making cities and buildings more sustainable, with a total estimated impact of 4 million European citizens who have heard about these activities organised in 12 European countries by 10Action.

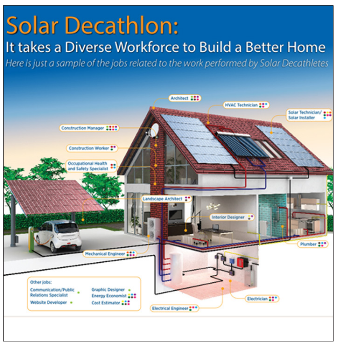


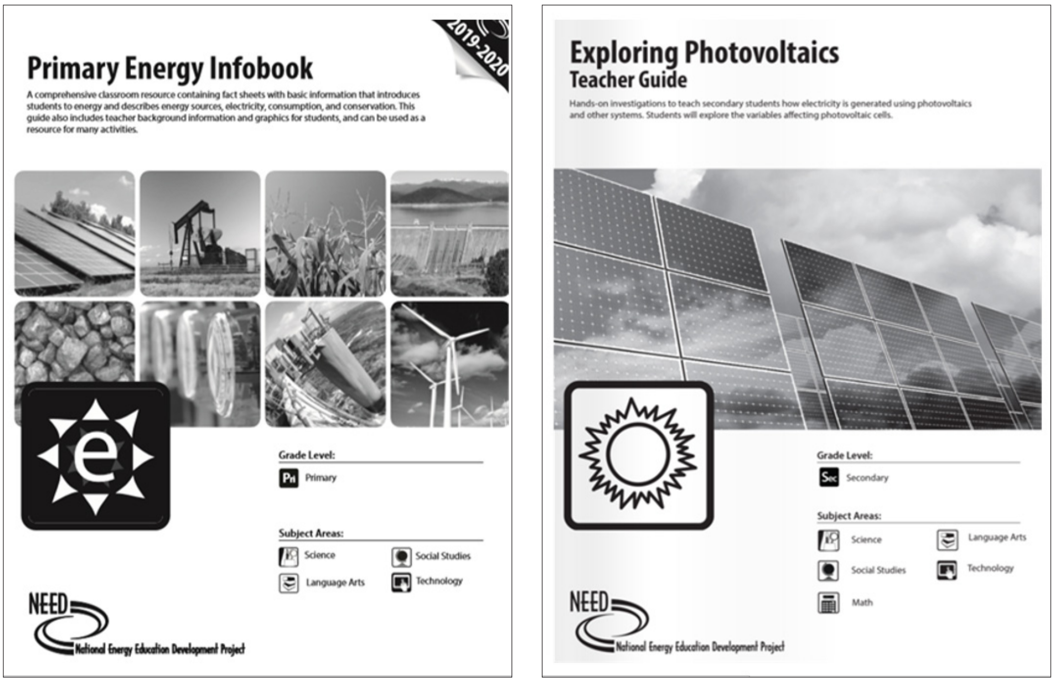

Figure 4.31: Educational material.

SDE12 benefited from the implementation of an extensive programme of educational and awareness-raising activities for all ages, many of which were organised by the 10Action team. Despite the impact of the crisis and budget cuts, 220 000 visitors to the solar village visited the houses and took part in the organised educational activities. SDE14 continued with similar social awareness objectives, but the budget cuts resulting from the crisis, the absence of a European framework programme such as 10Action, and the location selected for the solar village, reduced the number of visitors. However, there were still more than 85 000 visitors to this edition.

The success of the European and Chinese editions in the Solar Decathlon Competitions, encouraged a greater interest in the development of strategies and the organisation of activities to promote the education and social awareness of young professionals and the public in the American Competitions. However, the relocation of the Competitions from Washington (where the first five editions were held) led to a progressive reduction in the number of visitors to the California (SDUS13 and SDUS15) and Denver (SDUS17) editions, in all cases due mainly to the remoteness of the locations of the solar villages in the cities, and limited public transport, while the number of activities organised for children by staff and the general public increased. The process of reflection associated with the evolution of Solar Decathlon has led to a change in the format of these university Competitions, with a result that is not yet possible to assess, given that the first edition with the new format will be held in this year 2020.

In any case, as stated on its website ([https://www.solardecathlon.gov/education.html](https://www.solardecathlon.gov/education.html)), The U.S. Department of Energy Solar Decathlon offers a powerful learning experience for more than the competitors. Homeowners and consumers, building industry professionals, students and educators can explore these educational resources to learn more about renewable energy and energy efficiency. They have a complete list of educational resources to complement solar and energy efficiency courses as well as energy career resources, for both professionals and children & teenagers students, based on NEED's work (National Energy Education Development Project).

Figure 4.32: Teaching material.



solar
decathlon
europe

In the last edition of SDE19 held in the Hungarian city of Szentendre, the number of visitors was reduced as a consequence of the location of the solar village, poor public transport, and a lack of strategy to organise activities that would attract the public, and allow the promotion of education and social awareness of citizens. Competitions held in Latin America have brought together many visitors, with a high potential for social awareness. Other Competitions held in Morocco (Solar Decathlon Africa 2019) or in Dubai, UAE (Solar Decathlon Middle East 2018) have also had little impact in this regard too.


Figure 4.33


Figure 4.34

Figure 4.33: Inauguration. June SDE14.

Figure 4.34: School visit in SDE12.

4.2.3.1 Awareness activities and education of visitors in Solar Decathlon Europe Competitions

The strategy to promote the education and awareness of the citizens who visited the Solar Decathlon Europe Competitions has varied from one edition to another, with the difference between the first three SDE editions 2010, 2012, and 2014, where this objective was clear, and the last one held in 2019, at which it was not considered a priority objective.

In the first three editions, beyond the activities developed by related projects such as 10Action, which allowed activities to be carried out in 12 European countries, the objective of taking advantage of the related Competitions and events for the education and awareness of citizens, the strategy was based in attracting members of the public of all ages to the solar villages, and organising activities for each of the target groups that were defined. In this sense, it should be noted that one of the lessons learned from SDE10 was that the holding of the Competition in June, with the colleges and universities closed, did not allow for the successful organisation of activities for children and young people. Therefore, the 2012 edition of the SDE was organised in September, allowing 5 000 children and adolescents who participated in our activities, or 2 000 University students who made study visits during the assembly and disassembly processes. One of the key drivers for attracting audiences of all ages was to organise specific activities for each target group, which are described in more detail in Thematic Report 3.

Workshops were organised for the children and teenagers (with or without their families), in which specific activities were developed for each age group, such as drawing and painting rooms, clues to discover the solar village, etc. for the youngest; or workshops to design your own city, solar inventions, 'Focus on energy' photographic Competition, etc. for the teenagers.

solar
decathlon
europe

Figure 4.35: Professionals Event in SDE12.

Figure 4.36. Professionals Event in SDE14.



In all of the editions of SDE, attempts were made to organise school visits to the Solar Villa, and develop educational activities for children, although only in the SDE12, at the beginning of the school year, were there systematic school visits from Madrid with a real programme of playing and educational activities, with the full complicity of their teachers. Many of these schools ended up collaborating for more than a year in activities linked to the 10Action project.

Another of SDE's target groups has been professionals, for whom multiple visits and activities have been organised in the four editions of Solar Decathlon Europe. Activities, conferences and workshops have been organised sometimes by the sponsoring companies themselves (for example, Schneider Electric in the first three editions), and other times by partner companies, by national or International organisations, or professionals that have organised congresses and meetings, or by the organisers themselves.

Of special significance is the synergy with 10Action during SDE12, which resulted in the organisation of 21 workshops, talks, and conferences held at the Villa Solar during the Competition, with an average capacity of over 150 people (some up to 300 people).
In addition to these events, dozens of visits to the Villa Solar were organised for professionals, both during the assembly and disassembly phases of the houses, as well as during the Competition itself. A total of 6 000 professionals participated in some type of activity. All of them without counting the multiple exhibitions of models, participation in construction and energy fairs, national and international congresses, conferences organised in Spain and European countries, up to 43 854 professionals who have participated in activities organised throughout Europe, and which are described in the Thematic Report 3.

Many professionals from the world of architecture and construction engineering, took part in the Solar Decathlon Competitions. However, the level of environmental awareness and innovation achieved from a practical point of view has not been excessively relevant, as can be seen in the 2020 survey of professionals who attended the Competition: 3.44 out of 6, with a wide dispersion of answers. On the question of whether, after attending or visiting a Solar Decathlon Competition, the professionals decided to acquire training in new sustainable technologies, it can also be observed a wide dispersion of responses with an average value of 3.72 out of 6.

solar
decathlon
europe

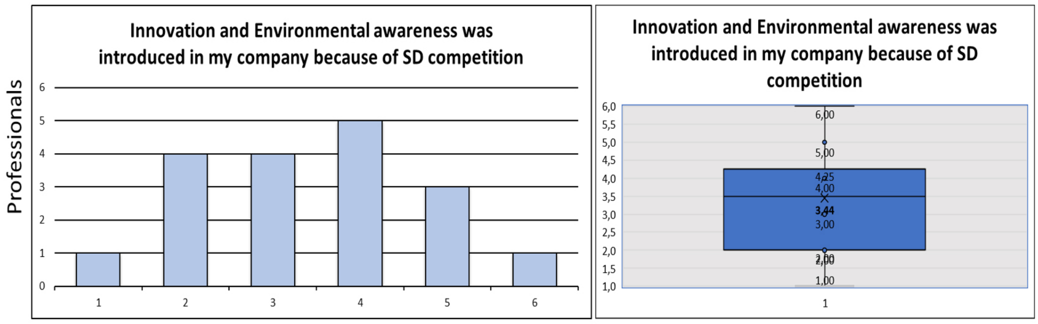



Figure 4.37: Professionals answers. SDE20 Survey.

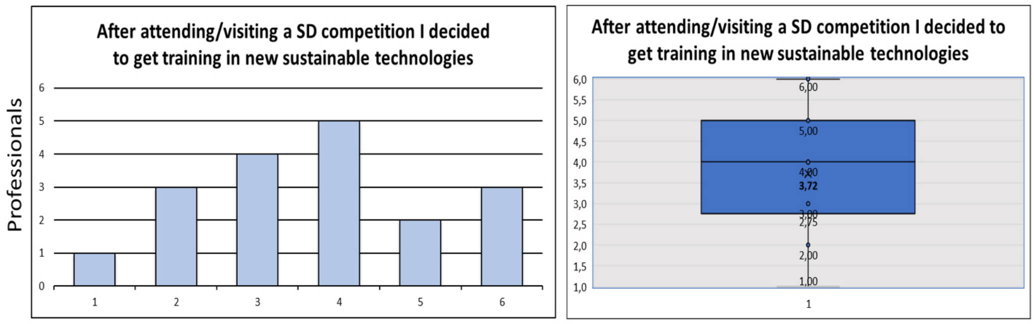



Figure 4.38: Professionals Event in SDE14.

Although the sample of answers obtained by professionals in the survey is reasonable overall, it is not considered sufficiently representative to make a distinction between the results of some Competitions and others, but from a simple observation of them, differences can be seen. The education and social awareness of the general public, of citizens, is one of the key drivers to assess the impact of a SDE Competition, and for that there are several factors that are important to achieve a high social and media impact such as a good location in a central and well-attended area of the city, good public transport to access the area, a dissemination campaign in the city and in the media to draw attention to the event, the preparation of a programme of attractive activities for the families, so that they can go with their children with some guarantee that they will have a nice time.




Figure 4.39: Public visits in SDE14.
Figure 4.40: Public visits in SDE10.
Figure 4.41: Public visits in SDE12.

Unfortunately, the organising teams have historically had little margin to select the location of the Solar Villages, coming in many cases from the cities and the technical constraints of the organisation of the Competition itself (cranes and trucks of great size and tonnage). What is in the hands of the organising teams, although with little margin from the budgetary point of view, is the organisation of attractive activities for families, and the promotion in the city and in the media.

solar
decathlon
europe

Despite all the budgetary limitations suffered by all the editions of SDE so far, the social and media impact achieved with the Competitions in Europe has been very relevant, with 192 000 visitors in SDE10 and the highest media impact of the European editions; 220 000 in SDE12 with an equally high media impact; 85 000 in SDE14; and some 15 000 in SDE19 during the Competition period, even though the Villa Solar has continued to be set up as a National Sample House Park demonstrator for many more months, open to visits from schools, professionals and the general public. This impact is far from that achieved in the two Chinese editions of Solar Decathlon, with an average of over 400 000 visitors, but significantly higher than the rest of the editions held in the world. The average of the first editions in the United States was around 100 000 visitors on average, and decreased significantly in the California, and later Denver editions. While the Latin American editions have also attracted a significant number of visitors, the editions from Africa, and especially the Middle East, have registered a low number of visitors because they prioritized other objectives.


Figure 4.42

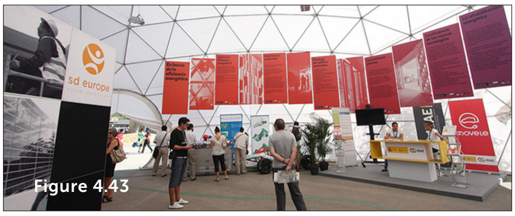


Figure 4.43

Figure 4.42: Public visits in SDE19.

Figure 4.43: Public visits in SDE10.

The success of the first two editions held in Madrid in terms of audience and media impact has different explanations with the common denominator of an organising team from the Universidad Politécnica de Madrid, with clear objectives in relation to the importance of attracting as many people as possible to educate and raise awareness among citizens.
The SDE10 edition benefited from the novelty of being the first European edition, a more central, visible and accessible location than the second one (next to the Manzanares river, a usual place for Madrilenians to walk). It also had the full and active support of the Spanish government, which resulted in the visit of the European Union's housing ministers, many government ministers, the Prince of Spain (now the King of Spain), etc., which in turn generated a great media interest. The Solar Villa was open for a week of Competition and the weekends before and after it (10 days in total), and many activities were organised for all audiences.

The edition of the SDE12 Competition was located in a more attractive area in terms of landscape, but less accessible to the public, although the means of public transport were reinforced from various areas of Madrid, as well as from the nearby metro station. With the change of government in Spain, the support for the Competition was substantially reduced, as was the availability of the budget, which was cut by two million euros. The experience gained in organising the first edition, the synergies with the European 10Action project, the extension of the Competition by another week (a total of 17 days), the transfer of the Competition to September, and the large number of activities developed throughout the Competition for all audiences (less than half of the activities initially planned were carried out due to budget cuts) meant that, with a lower media impact, the total number of visitors was higher than in the first edition.

In this edition of SDE12, a special effort was made to raise public awareness, organised around five major areas for general public designed to inform and raise the awareness of citizens on specific issues: IDAE's site on energy saving and what each citizen can do about it; Ministry/UPM's site on sustainable development and energy efficiency in buildings and cities, and energy retrofitting; electric car area, on sustainable mobility; renewable and clean energy technologies on the different solar, geothermal, hydrogen, wind technologies, etc; and smart grid centre (developed by Schneider) with the monitoring of the smart grid of the solar village and its management system.

Although the surveys carried out in 2020 on visitors to the Solar Decathlon Competitions are not representative due to the low number, it is still interesting to confirm that 100% of those surveyed agreed that the visit to the Villa Solar was worthwhile, that they would recommend the visit to others, that they had heard about the Solar Decathlon Competitions before their visit, that if they had the opportunity they would visit a new edition in the future, they had noticed changes in their city because of SD Competition, or that they had learned about sustainability at Solar Decathlon. 75% of those surveyed agreed that SD had influenced renovation decisions at home, and lifestyle decisions with them or their family.

4.2.3.2 Awareness activities and education for university students linked to SDE.

The educational values, knowledge and skills developed by university students who have participated in Solar Decathlon Competitions have been documented simply by participating as Decathletes, and often reinforced with activities and initiatives organised by the universities, or by the Competition organisers. Beyond these values, the organisers of the Competitions and linked events, and of initiatives such as 10Action, have organised multiple activities in each edition aimed at the education and social awareness of university students, in whose hands lie the most immediate future, and the firmest bet of a next generation of professionals committed to the environment and a more sustainable world.

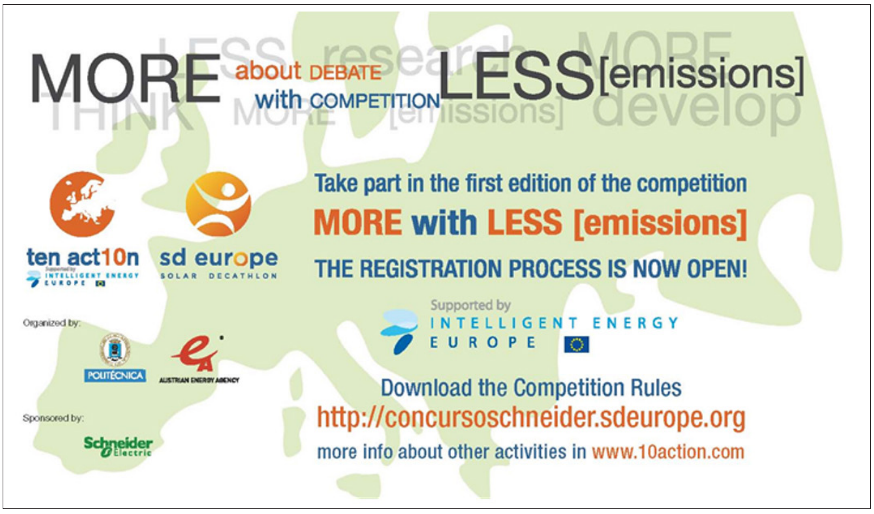



Figure 4.44: 10Action 'More with less (emissions)' Competition


Figure 4.45. UPM's summer school, Sustainable Architecture.


Figure 4.46: Visits of the houses in their countries - 10Action

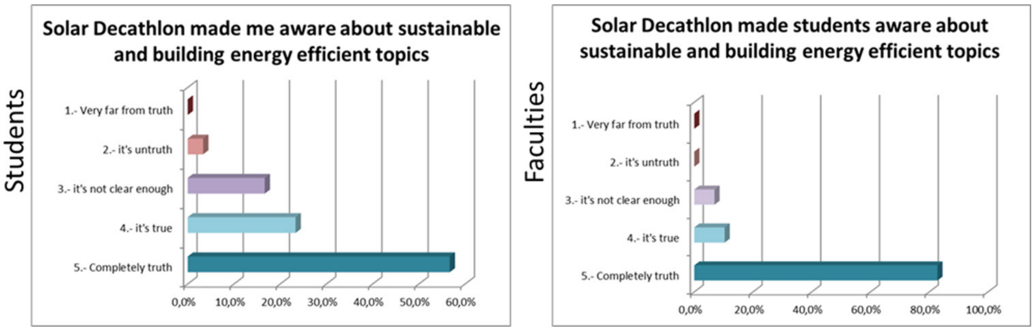
In three of the four European editions of SDE, the Competition was held in June or July, outside the universities' course calendar, which resulted in a less systematic participation of university students. Even so, university activities were organised both during the Competitions and during the period of the 10Action project, with visits and activities by university students in the European countries of the competitors in SDE10, courses and conferences, teaching material prepared for European university professors on sustainability, energy efficiency and energy renovation, university workshops and debates such as 'More with less (emissions)', or summer courses organised by the Universidad Politécnica de Madrid. In total, 2 086 university students from 12 European countries have participated in the workshops, conferences, debates and Competitions organised by 10Action.

Figure 4.47. Visiting group of university students in SDE12 in Madrid.

During the SDE12 Competition held in September, coinciding with the start of the university course, visits were organised for groups of university architecture and engineering students, from public and private universities, in Madrid and other cities in Spain, both during the assembly phase of the houses and during the Competition itself. In conjunction with these visits, workshops were also organised with each of the six juries who evaluated the evidence in the Competition, lectures by some of the most distinguished jurors, technical explanations of the strategies and technologies of each of the competing houses, as well as other courses and conferences organised for the professionals. 2 000 university students, apart from the Decathletes, participated in these study visits and associated activities.

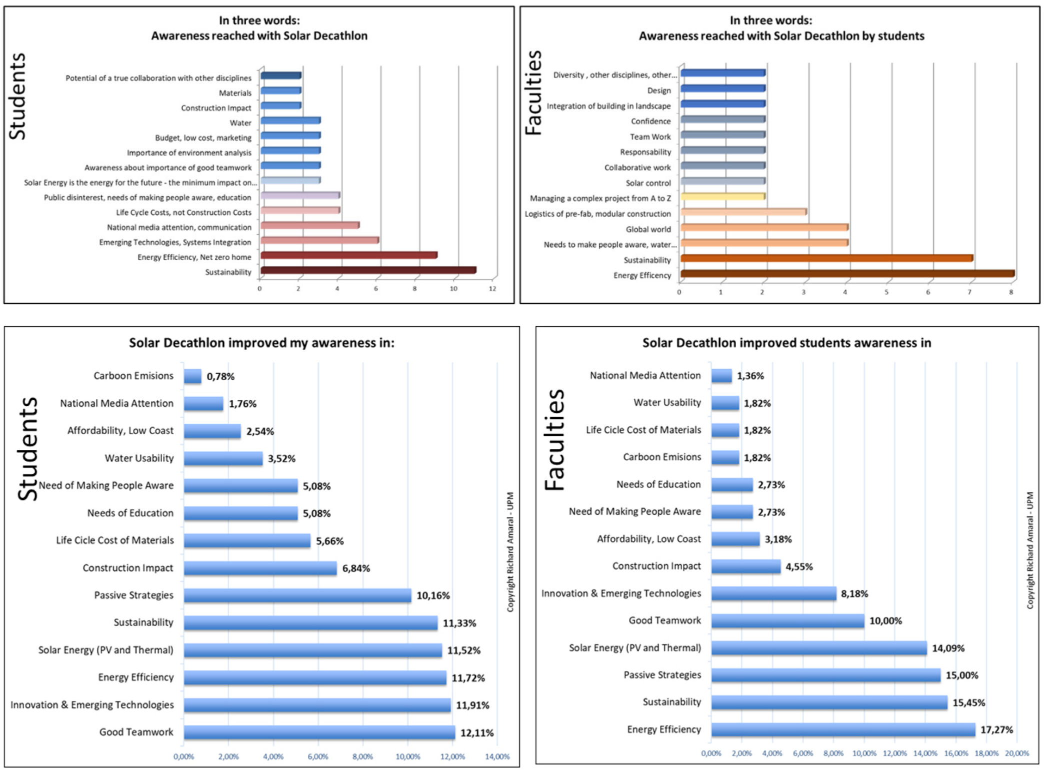
solar decathlon europe

Figure 4.48: SDE14 Survey.




According to the SDE14 survey, there seems to be a consensus that Solar Decathlon has raised awareness among students about sustainable and energy efficiency issues in buildings.
The average rating of the students in this regard is 4.21 out of five, with 78% of the students stating this. Professors also supported the statement with 90%, with an average of 4.63 out of five. In terms of where social awareness was highest, freely defining three words, students highlighted sustainability (10.9%), energy efficiency (8.8%), integration of emerging technologies (5.9%), communication and media attention (4.9%), life cycle cost (3.9%), and social awareness & education (3.9%). On the other hand, Professors also emphasized energy efficiency (7.9%), sustainability (7.9%), social awareness (3.9%), Global world (3.9%), and industrialized modular construction (3%).

Figure 4.49: SDE20 Survey.

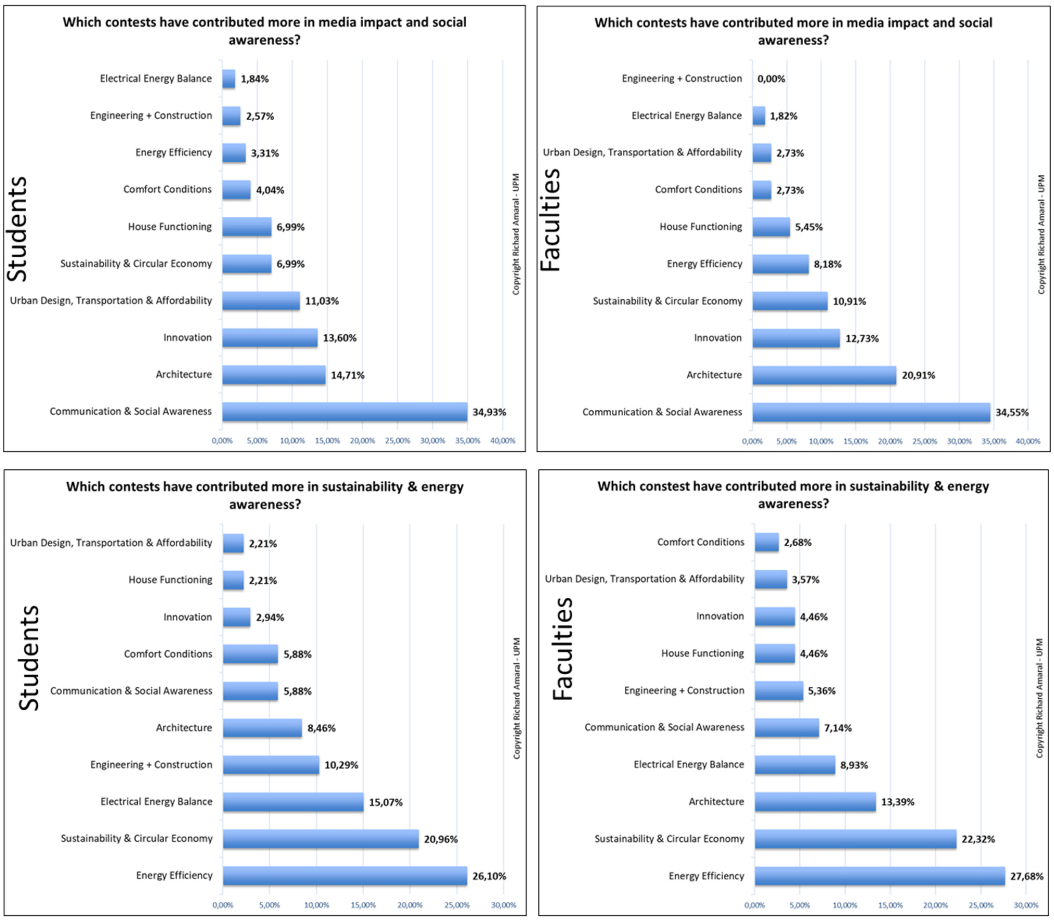


solar
decathlon
europe

Results are similar but with some differentiating nuances in the 2020 surveys. For example, students highlighted teamwork (12.11%), innovation & emerging technologies (11.91%), energy efficiency (11.72%), solar energy (11.52%), sustainability (11.33%), and passive strategies (10.16%). Less variation is observed in the professors' scale of assessments, with the emphasis on energy efficiency (17.27%), sustainability (15.45%), passive strategies (10.16%), solar energy (14.09%), teamwork (10%) and innovation& emerging technologies (8.18%).

It is also interesting to look at the impact of the Competition contests on social awareness and media impact, or on issues of awareness regarding sustainability and energy efficiency. With respect to the first, it is worth noting the agreement between students and professors regarding the potential of the contests on communication & social awareness, architecture, and innovation. The students also pointed out the contests on urban design, transport and affordability, sustainability & circular economy, and the functioning of the houses; while the professors highlighted the contests on sustainability & circular economy, energy efficiency, and functioning of houses.

Figure 4.50: SDE20 Survey.



With regard to the most influential contests for sustainability and energy efficiency awareness, students and professors coincide with the contests of energy efficiency, and sustainability & circular economy, although later students highlight the contests of energy balance and engineering & construction, while professors highlight architecture, energy balance, and communication & social awareness.

### 4.2.4 Perception of the educational potential by the key SDE stakeholders

From the detailed analysis of the SDE14 surveys and that carried out for this 2020 study, there is no doubt that the main focus of the Solar Decathlon Europe university Competition has been on the education and social awareness of the young university students, professional architects and engineers of tomorrow, who have in their hands the construction of more energy-efficient and sustainable buildings and cities.

For example, with the total number of answers in the 2020 survey, to the question of scoring from one to six the extent to which some of the objectives of the SD Competition have been achieved, it should be noted that in practically all cases average values of more than 4 out of 6 have been obtained, with a variability of these averages between 3.98 and 4.88, which represents a reasonable perception of the fulfilment of these objectives, taking into account the different performance of the various editions of SDE, and as was explained in the introduction, it has not been intended to analyse them in a differential manner, but as a whole.

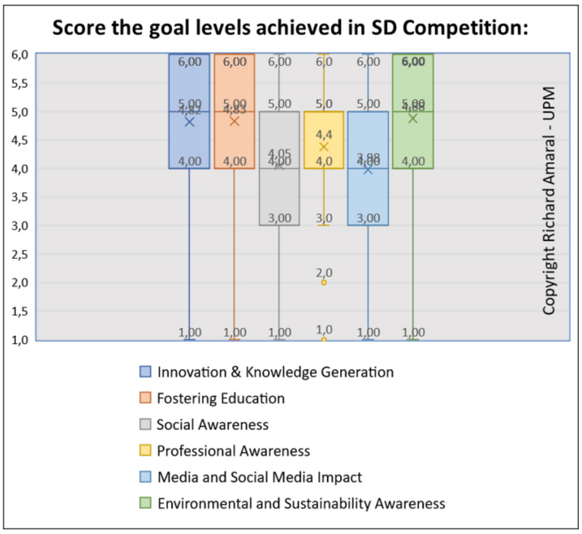



Figure 4.51: SDE20 Survey.

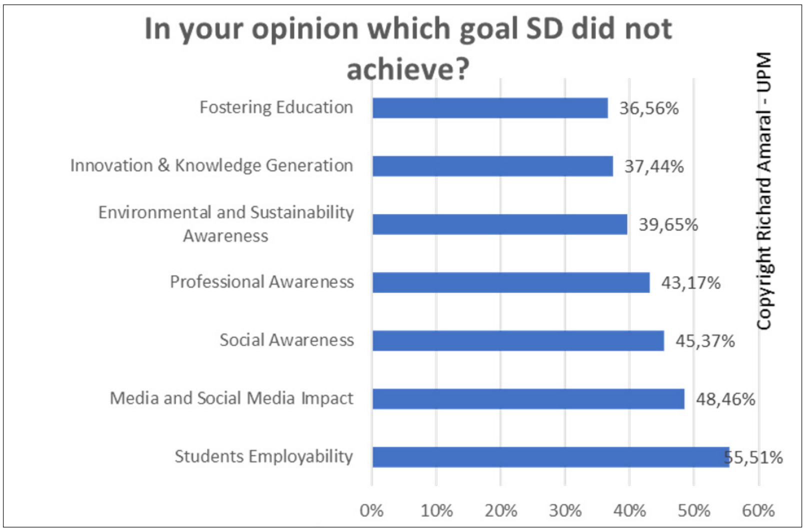



Figure 4.52: SDE20 Survey.

The average value obtained for the objectives, in order of the best or worst value, was environmental and sustainability awareness 4.88 out of 6; fostering education 4.83 out of 6; innovation & knowledge generation 4.82 out of 6; professional awareness 4.38 out of 6; social awareness 4.05 out of 6; media and social media impact 3.98 out of 6.

With a similar question asked in the negative, most of the respondents in 2020 awarded value as objectives perceived as best achieved: fostering education, innovation & knowledge generation, environmental and sustainability awareness, professional awareness, social awareness, media and social media impact, and finally student employability.

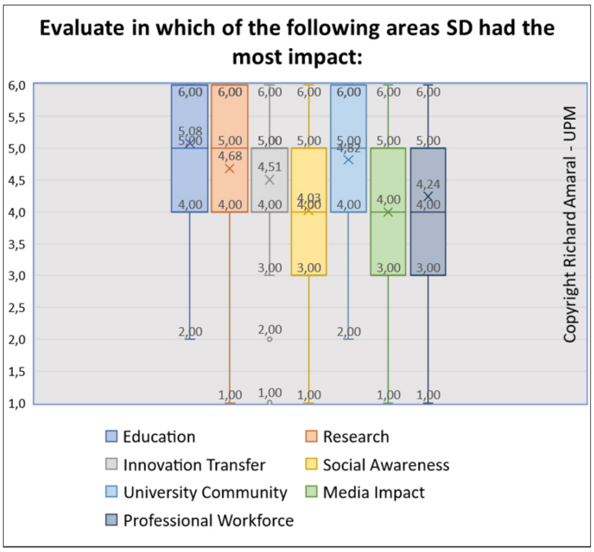



Figure 4.53: SDE20 Survey.

Analysing some of the areas of greatest impact achieved with the Solar Decathlon Competitions, it is worth highlighting first the positive assessment achieved in the area of education, with a 5.08 out of 6. This is followed by the impact on the university community with an average value of 4.82 out of 6, research with 4.68, innovation transfer with 4.51, professional workforce with 4.24, social awareness with 4.03, and finally the Media impact with 4 out of 6. It is also worth mentioning the high rating of the impact of the SD Competitions in all the selected areas, considered by the majority of the surveyed people.

It is remarkable that in the 2020 survey 100% of the people surveyed stated that they consider the Solar Decathlon to be a positive overall experience. Asked later as to the main reason they are satisfied with SD, the overall opinion of the respondents was as follows: innovation & knowledge generation 64% (which goes up to 69% in the case of student estimation), environmental and sustainability awareness 48% (49% students), fostering education 43% (similar for students), professional awareness 40% (45% students), student employability 40% (43% students), social awareness 38% (40% students), media and social media impact 36% (39% students).

solar
decathlon
europe

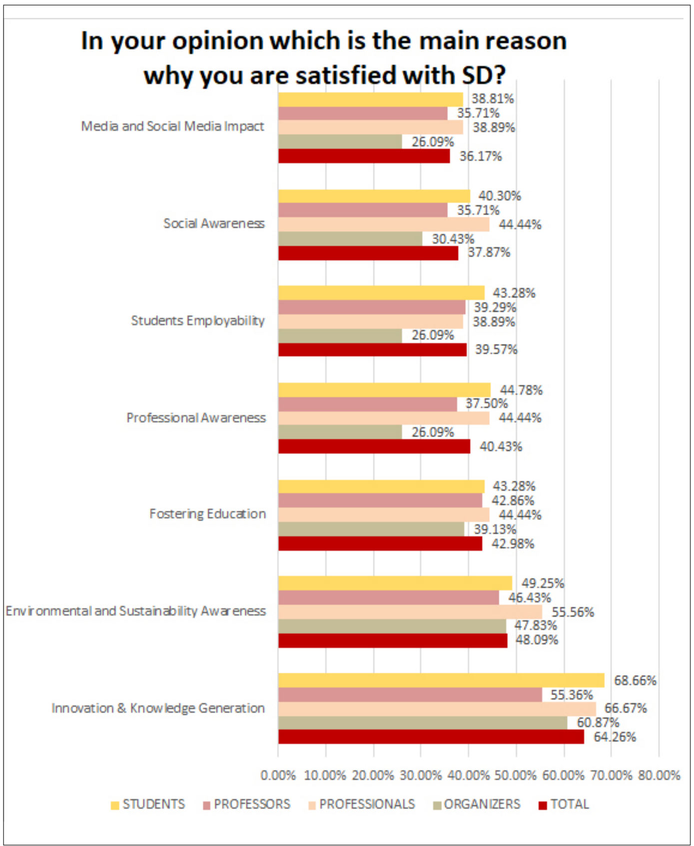



Figure 4.54: SDE20 Survey.

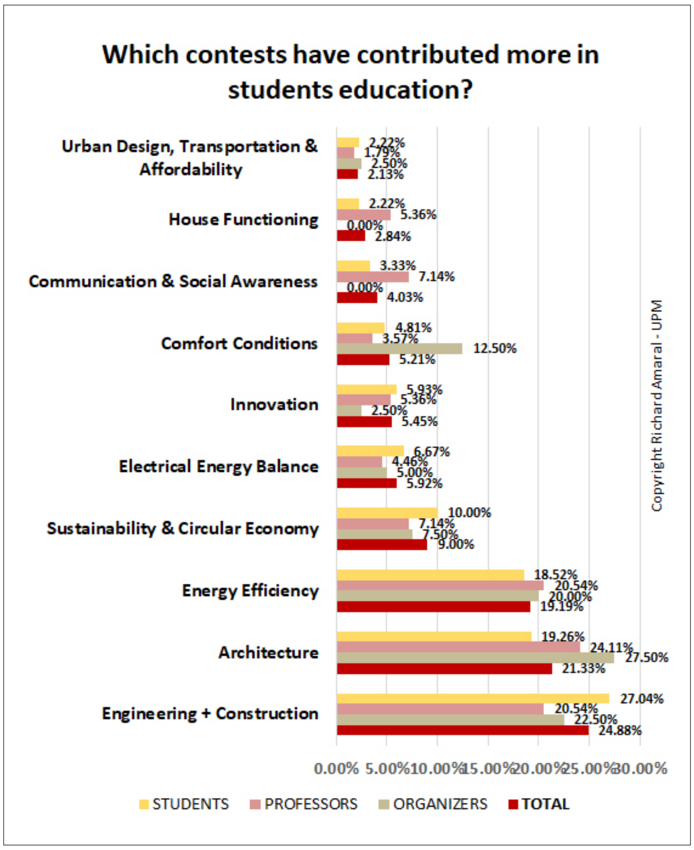



Figure 4.55: SDE20 Survey.

For a correct interpretation of these results it should be clarified that respondents could choose only one option from among the reasons selected, among which there was a last option to select all of them. 34.89% of all people surveyed in 2020 selected this option out of all of them, which rises to 38.06% in the case of students surveyed, 38.89% in the case of professionals, and it falls to 32.14% in the case of professors and 26.09% in the case of organisers. The attached graph considers the percentage accumulated with the individual choices.

As regards the opinion of the survey respondents on which contests have contributed most to the education of students, considering that they could choose only two of the ten contests, the total average estimate of the most significant were engineering + construction with 24.88% of the choices, architecture with 21.33%, energy efficiency (19.19%), sustainability & circular economy (9.00%), and with smaller percentages electrical energy balance, innovation, comfort conditions, communication & social awareness, house functioning, urban design, transportation & affordability.

solar
decathlon
europe

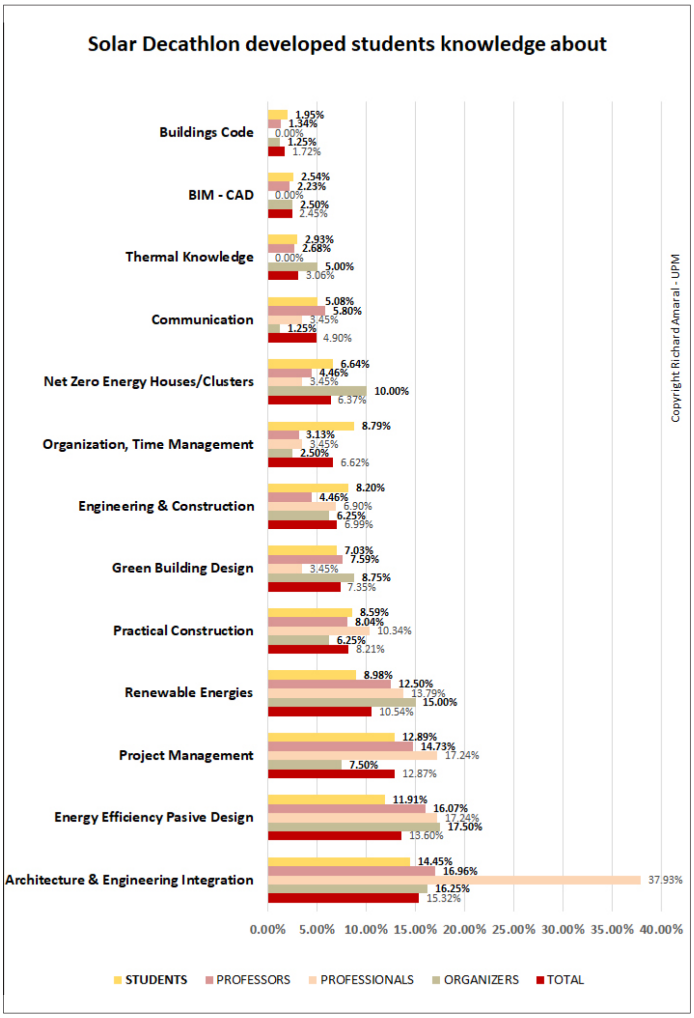



Figure 4.56: SDE20 Survey.

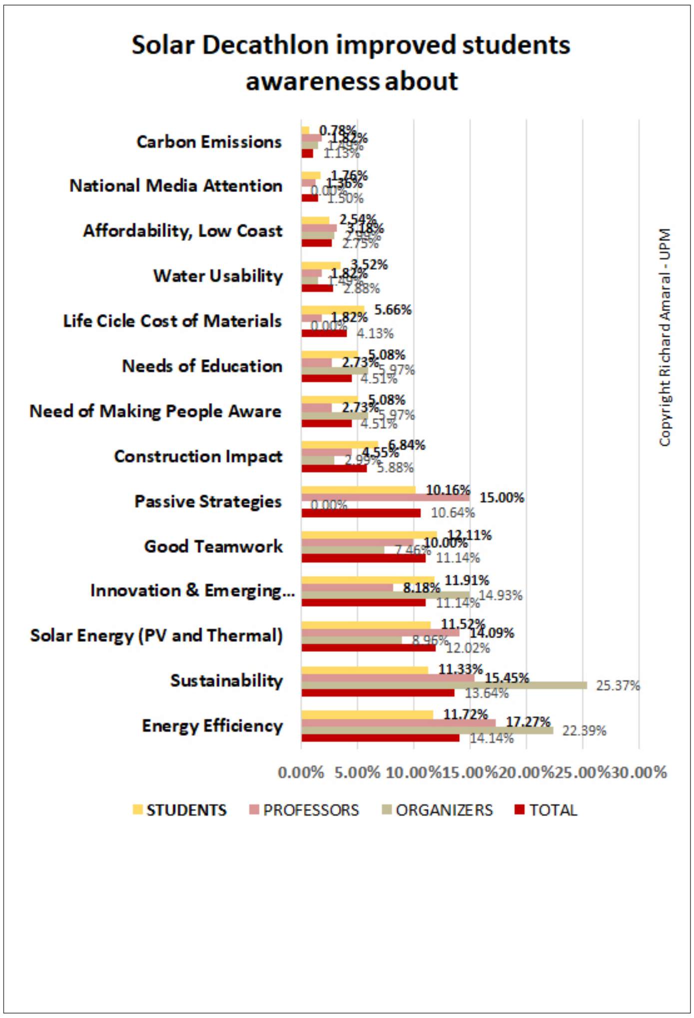



Figure 4.57: SDE20 Survey.

Students have a similar perception on all the contests, although with small variations in the percentages. However, professors and organisers consider that the most relevant contest for the education of students is architecture, with 27.5% for organisers and 24.11% for professors. It is also worth noting that the organisers gave the contest on comfort conditions a higher score, with 12.5%, compared to 5.21% for the total number of respondents.

In order to establish the subjects in which students have acquired the most knowledge through the Solar Decathlon Competitions, the 2020 survey asked students, professors, organisers, professionals, and the general public the question encouraging them to select the 4 most significant Knowledge areas from a list selected from the results of the SDE14 survey.
The total score of the respondents in the main subjects was architecture and engineering integration (15.32%), energy efficiency and passive design (13.60%), project management (12.87%), renewable energies (10.54%), and already below 10% practical construction, green building design, engineering & construction, organisation, time management, net zero energy houses/clusters, communication, thermal knowledge, BIM - CAD, o buildings code.

solar
decathlon
europe

Students and professors have a similar scale to prioritize these topics of knowledge, with small differentiating nuances and figures. The high percentage that professionals give to the integration of architecture and engineering as the main knowledge acquired by the students with the Solar Decathlon is very significant, with 37.93% compared to the average of 15.32%. In relation to the topics in which Solar Decathlon improved the awareness of students, by selecting 4 from those surveyed on the list selected based on the SDE14 survey, the most notable were energy efficiency with 14.14% (of the total), sustainability 13.64%, solar energy (pv and thermal) with 12.02%, innovation & emerging technologies 11.14%, good teamwork 11.14%, passive strategies 10.64%, with all other subjects below 6%: construction impact, need of making people aware, needs of education, life cycle cost of materials, water usability, affordability, low coast, national media attention, carbon emissions.

Professors and students rank the subjects with similar criteria to those of the total number of people surveyed, while the organisers value sustainability significantly higher with 25.37%, energy efficiency with 22.39%, and Innovation & Emerging Technologies 11.14%. Selecting two each of the survey respondents in 2020, the contest that has contributed the most to social awareness in sustainability and energy efficiency is the contest energy efficiency with a total of 27.96%, reaching up to 40% according to the organisers. Sustainability and circular economy with 20.85%, electrical energy balance 13.51%, architecture with 9.24%, are the other most influential contests.

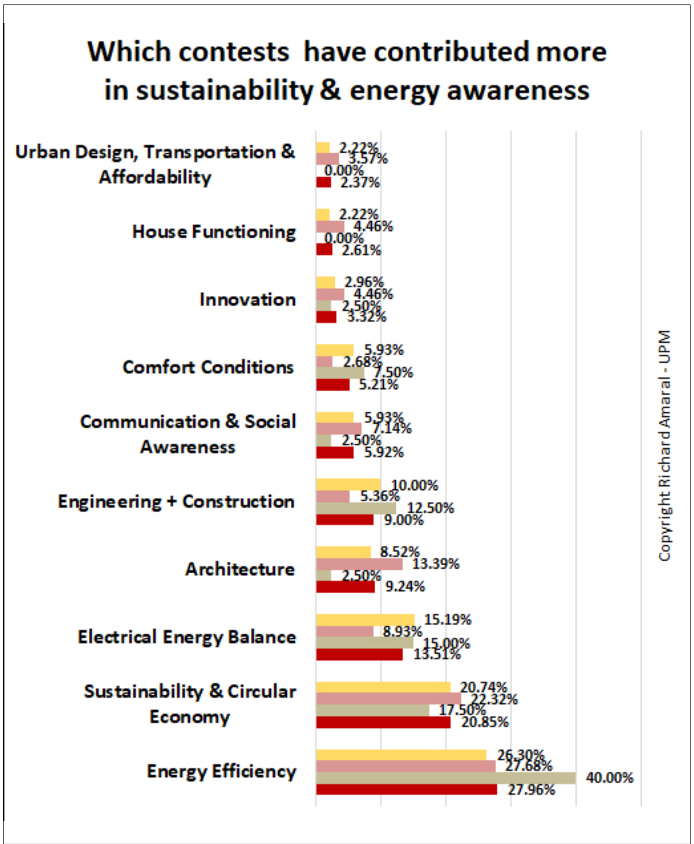



Figure 4.58: SDE20 Survey.

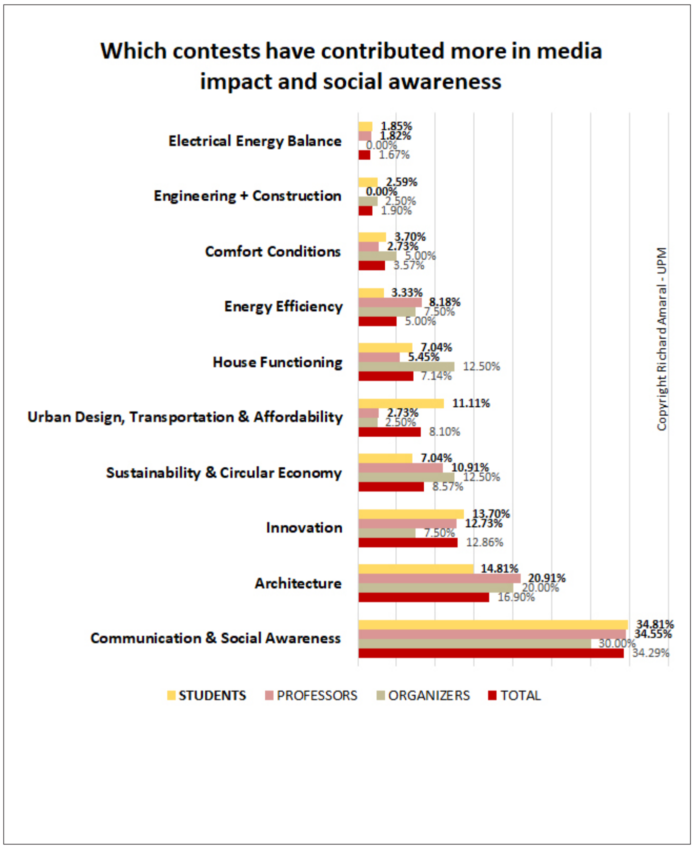



Figure 4.59: SDE20 Survey.

solar
decathlon
europe

There is greater overlap between the groups of survey respondents in the choice of two contests in the Solar Decathlon Competition events that have contributed most to media impact and social awareness. By a large majority and unanimously, the most effective contest in this regard was the communication and social awareness contest with 34.29% of the total number of respondents. architecture with 16.9%, innovation with 12.86%, and sustainability and circular economy with 8.57% of the total, are other contests that have also been influential.

It is remarkable that despite the diversity of contests in the Competition, all of them show a greater or lesser influence on both the media impact and social awareness, as well as on sustainability and energy awareness.

Finally, mention should be made of the personal skills developed by the students during the Solar Decathlon Competitions. In point 4.3 there is an analysis of the main skills surveyed in which it must be highlighted that all of the skills selected were highly valued by all of the people surveyed, with measured values ranging from 4.55 points out of 6 in the lowest case to 5.43 points in the best valued case.

solar
decathlon
europe

## 4.3 requested committed workforce profiles

The shift to a low-carbon economy implies structural changes across sectors and occupations as new 'green' occupations have arisen or grown in demand. Energy efficient and sustainable buildings will play a key role in order to remain on track to full decarbonisation.
However, installing the technologies needed to make Europe's building stock greener requires a skillset that the construction industry can struggle to supply.[1] The construction sector has been affected by a skill mismatch. The difference between the qualification level of jobseekers and the job requirements can take the form of over qualification or under qualification.
The construction sector in Europe has one of the highest levels of over qualifications, with about one third of workers being overqualified for the job they do.[2] Skill shortages and mismatches in the construction sector are associated with several structural barriers: the decrease in the number of young skilled workers, the ageing of the construction sector's workforce, migration, and the misalignment between vocational and educational training (VET).

At the same time, innovation in the sector and EU regulation are creating new drivers for the development of the sector and desired skills for its workers. Some of the skills acquiring greater importance include management, planning, numeracy, and communication skills, as well as ICT, renewable energy and energy efficiency skills. Although training in green building skills has increased over recent years, employers still face difficulties in finding qualified people to undertake certain jobs. Greater coherence and coordination between education, training, employment, and low-carbon policy will be needed to engender an effective job-rich, sustainable energy transition.

As described in detail in the European Construction Sector Observatory analytical report on 'Improving the human capital basis'[3], the energy efficiency targets need a transformation of the skills required during all stages of the building process, from planning to design, production, maintenance and renovation and finally demolition (Figure 4.60).

[1] Skills for green jobs: 2018 update: European Synthesis Report. Cedefop. Luxembourg: Publications Office of the European Union, 2019

[2] European Parliament, Labour market shortages in the European Union. March 2015. http://www.europarl.europa.eu/RegData/etudes/STUD/2015/542202/IPOL_STU(2015)542202_EN.pdf

[3] PricewaterhouseCoopers (PwC), European Construction Sector Observatory – Analytical report on TO2 - Improving the human capital basis, April 2017.

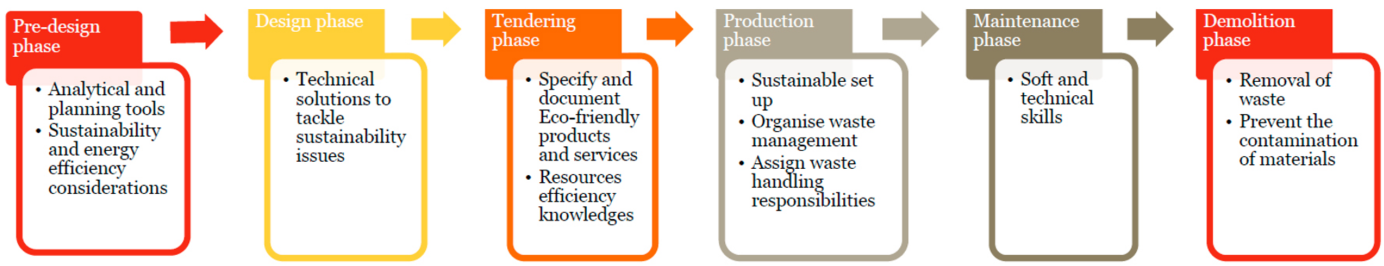



**Figure 4.60: Skill needs across the construction process (PwC / ECSO Analytical report TO2)**

At the pre-design phase of the project, the professionals will be required to have knowledge about any relevant climate considerations, appropriate passive sustainable design strategies and environmental resources, as well as an understanding of the energy performance goals of the final construction.

solar
decathlon
europe

During the design phase, professionals will need skills related to the technical solutions necessary to tackle and address such sustainability issues, for instance ensuring the final construction includes the necessary infrastructure to face longterm climate change challenges such as the increase in rainfall and flooding.

Similarly, during the actual production stage, site workers need to be trained to develop the necessary skills to carry out sustainable construction practices on-site, whereas managers will be required to have the skills to be able to organise the logistics of the construction process sustainably. In the maintenance/operation (+refurbishment) phase some of the key skill needs will include effective communication with clients regarding energy efficient renovation, installation of energy efficient building automation systems, post-installation follow-up services and enhanced cooperation among all professionals involved in this stage.

Finally, new skills will be increasingly needed at the demolition stage during the dismantling, reuse, recovery, or disposal of building materials. Consequently, workers skilled in the removal of waste from the site and in detecting leakages, pollution and emissions will be particularly sought-after in order to prevent the contamination of materials while project managers should provide the overall strategy and strategic knowledge to instruct and train the workers.

However, beyond tackling the problem with efforts to increase the levels of qualifications, it is important to notice that Member State economies are heterogeneous, and that needs for specific skills in the construction sector in the short term need to be contextualised, future needs for skills in the short term will be characterised by different levels of skill qualifications and education across countries.[4]

Skills in designing and conceiving new green buildings are likely to be appropriate particularly in emerging economies. For developed countries, the greater emphasis is likely to be on building energy retrofitting.

Research into the identification of skills shortages[5] indicates that sectors with critical shortage or surplus have important effects on national education and training programmes. Country level research suggests that architecture is a key occupation in developing green business, and one in which it can be difficult to find people with the right skills. For architects, as for engineers and consultants, technical skills (such as an understanding of passive design techniques and renewable energy technologies) are very important, but so too are softer skills, such as environmental awareness and an ability to communicate.

As well as the skills needed for the specific occupations, there is a set of core skills[3] which are needed by those working in all areas of green building. Given the rapidity of change, there is a requirement for adaptability to change. There is a need for adequate environmental awareness. Green building also calls for interdisciplinary skills, including the ability to work effectively with people from other disciplines as well as individually having skill sets which cross traditional occupational boundaries. Finally, teamworking, coordination and leadership skills are important core skills in all areas of green building.

[4] UEAPME, Business Europe, CEEP. The cost-effectiveness of apprenticeship schemes. 2016. https://be-extranet-prod.s3.amazonaws.com/publications/2016-05-27_employers_final_report_on_apprenticeships.pdf

[5] CEDEFOP, Skills shortage and surplus occupations in Europe. Briefing note, November 2016.

solar
decathlon
europe

Aligning the competences of the workers to the requirements imposed both by policy drivers and market demand will result in a more productive, profitable, and competitive construction sector. Solar Decathlon participates in the reduction of the aforementioned existing gap, regarding both technical skills (green building design, understanding of heating, ventilation and air conditioning systems, solar thermal and photovoltaic technologies, the energy efficiency characteristics of materials, energy monitoring....etc) and softer skills ( environmental and social awareness and communication).

Results of the Survey performed in 2020 approach this matter, students are asked about their perception. 100% of the students think their participation in SDE has enhanced their employability. They are also asked to score from 1 to 6 how much they consider SDE has enhanced their employability. Figure 4.61. shows their perception is SDE has indeed enhanced their employability scoring 4.22 on average.

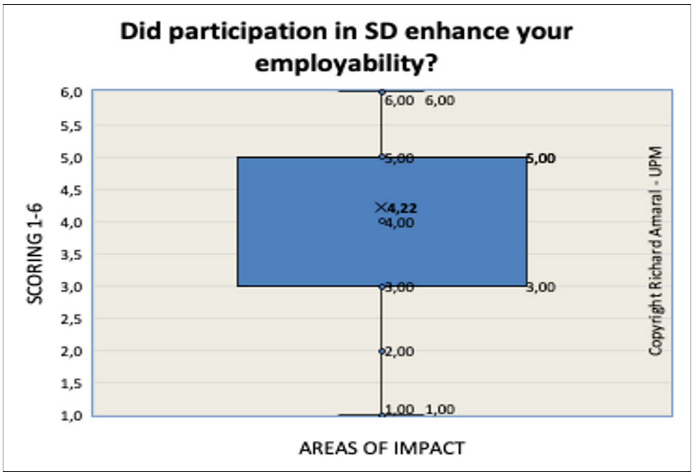



Figure 4.61: Students answer to "Did participation in SDE enhance your employability?" (SDE20 Survey)

**4.3.1 Enhancing professional capabilities through SDE**

The core skills[3] important in all areas of green building: adaptability to change, environmental awareness, interdisciplinary skills, cross traditional occupational boundaries, teamworking, coordination and leadership skills are empowered in Solar Decathlon Teams. These skills, particularly the soft skills, are not usually included in the curricula of technical degrees.

The main value regarding technical skills is that Decathletes put into practice the theoretical knowledge acquired during their university studies years, information regarding architecture, engineering, green building design, monitoring and data management and logistics. Project management is coordinated in a small but complex project which allows student to have an overall perspective of the building process. Students and professors taking part in Solar Decathlon acquired expertise that usually goes beyond their activity.

solar
decathlon
europe

As regards architects, they will take part in the building performance evaluation. The houses are not only designed and built using innovative sustainable criteria design and new technologies, but they are also tested. The Teams go through predesign, design, and production phase but not only that, they evaluate monitoring comfort parameters and energy performance, checking how solutions really perform. This is a valuable expertise. The requirement for monitoring building performance is currently being incorporated into European Building Regulations. The Solar Decathlon has implemented this testing in their houses since 2002.

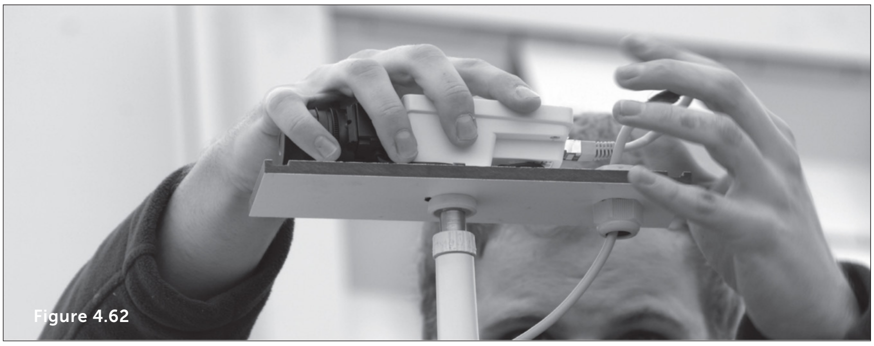


Figure 4.62

Figure 4.63

Figure 4.62: OTO Team in SDE12

Figure 4.63: OTO Team in SDE12

Solar Decathlon Teams usually consist of 30 or 40 members, the hierarchy is not always clearly established. Team structure is predominantly bottom up or quite democratic which leads to a need to develop tolerance and flexibility in the work process. The core skills important in all areas of green building are essential in this type of participatory and collaborative work structure, particularly adaptability to change and teamworking.

Teams competing in Solar Decathlon Europe are interdisciplinary including mainly architects and engineers but also students from other disciplines (environmental studies, building physics, communications, economy, marketing, graphic design, interior design, lighting design, social science, etc.) which teaches students to work in multidisciplinary Teams, to evaluate problems from different angles and to value the contribution of other disciplines to solve a common problem. In short, to be part of a solution without necessarily leading the way. Coordination and leadership skills are also empowered in Solar Decathlon Teams.

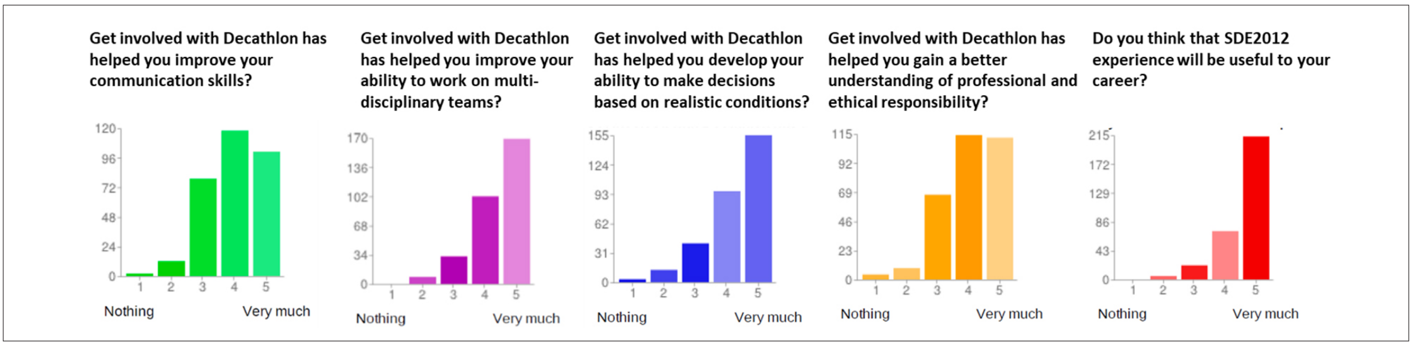
Some of the Teams are not only large and multidisciplinary but transregional and transnational. In these cases, the coordination difficulties are greater, but the educational value of the experience is too. Collaboration between countries working remotely is necessary to solve the global problems we face, students who have gone through this process will be better prepared to be part of international projects.

The educational value of Solar Decathlon Europe also addresses professors, for whom continuous learning is of great importance. During the Competition, they not only learn from putting the theoretical knowledge they teach into practice, but they are also part of a Team, they also develop skills in communication, teamwork and leadership skills.

solar decathlon europe

The student's acquisition of skills during Solar Decathlon Europe is diverse, depending on the student and professor's implication in the projects and the construction. The perception among the students as to the skills they developed with Solar Decathlon is high. In SDE12 students were asked to score how SDE has helped them to improve aspects such as communication skills, teamwork, multidisciplinary team working, etc (figures 4.64).

Figure 4.64: Students answer to SDE14 Survey.




In SDE14 the students and professors were asked the same question about the skills students developed with Solar Decathlon. The students' perception of the skills developed is high but a little bit lower than the perceived by the professors (figure 4.65)

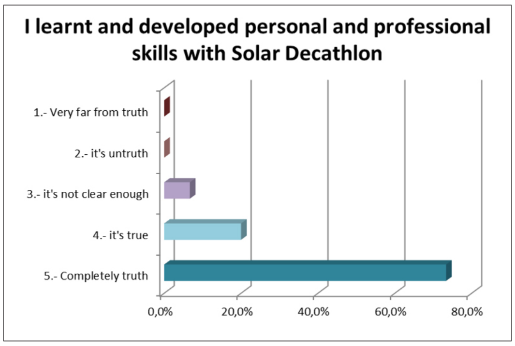



Figure 4.65: Students answer to SDE14 Survey.

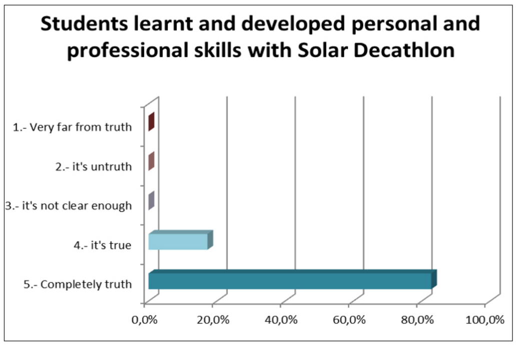



Figure 4.66: Professors answer. SDE14 Survey.

There are not usually specific training activities and Solar Decathlon is not used as a training program from the universities, as mentioned in the section 4.2.2.2 Comprehensive education, nevertheless, practical learning occurs even though it is not programmed (figure 4.66), it being a consequence of the accomplishment of the Solar Decathlon Europe challenges, both during the time of the project and the Competition event. When professors and students were asked to give a free answer about which specific professional knowledge the students developed in SDE, the answers of students and professors were quite in tune regarding the items they mentioned, professors think students especially develop 'Project management, materials, construction and facilities and design coordination' (figure 4.67), and students think they develop 'Architecture and engineering integrated design, materials and construction' (figure 4.68).

solar
decathlon
europe

They were asked to give a free answer about which specific skills the students developed in SDE, the answers of students show they perceive communication as the most developed skill (figures 4.69), in this item there is a big difference with professors, who do not seem to value this aspect (figures 4.70). Regardless of Communication both groups mentioned Project Management and Teamwork as the most skills developed. Environmental awareness is an important objective of Social Decathlon Europe. The benefits of the projects need to be communicated to different target groups (professionals, industry, students, public and children).

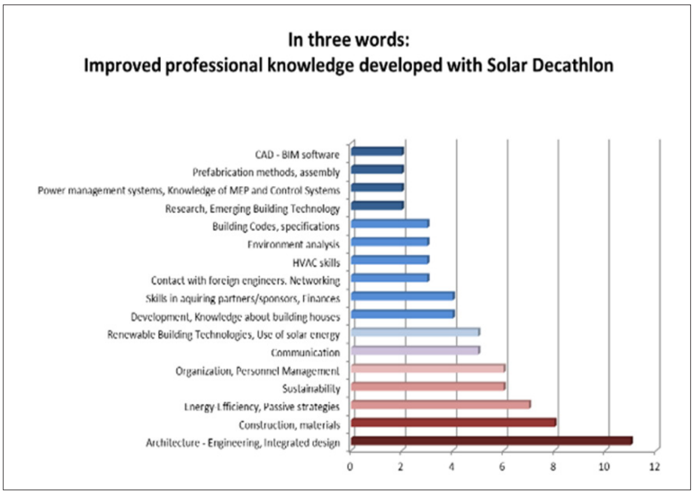



Figure 4.67: Students answer to SDE20 Survey.

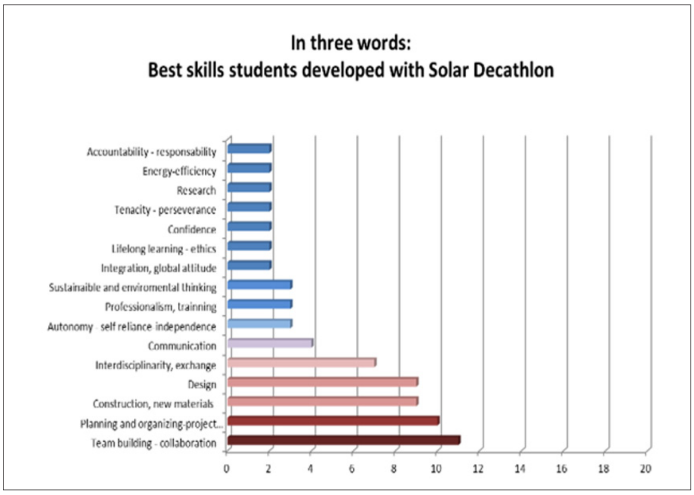



Figure 4.68: Professors answer to SDE20 Survey.

Most of the students must perform communication and awareness activities, for the first time in their life's, developing capabilities not explored so far, acquiring new skills, and overcoming awe. In this process of communicating there is a self-awareness, an interesting transformation experience by students and professors alike. Learning Solar Decathlon Europe potential is doubtless and has still to be optimised. To accomplish it there is much more that could be done. A protocol to guide Teams to optimize this potential should be developed approaching the aforementioned issues: team-work, multidisciplinary, collaboration, flexibility, tolerance, environmental awareness and integrating other issues needed to face the challenges of the future to enhance creative and thinking outside the envelope, not only in students, but professors, professionals and the public.

In the 2020 survey a similar open-ended question of naming three inspirational words that leverage opportunities and synergies which arise from SD workforce profiles, the most frequent were related to teamworking, friendship, participation, creativity, resilience, leadership, etc.

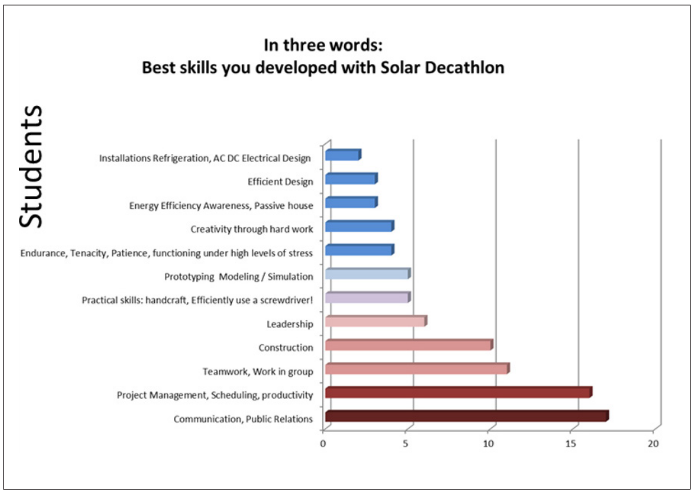



Figure 4.69: Students answer to SDE14 Survey.

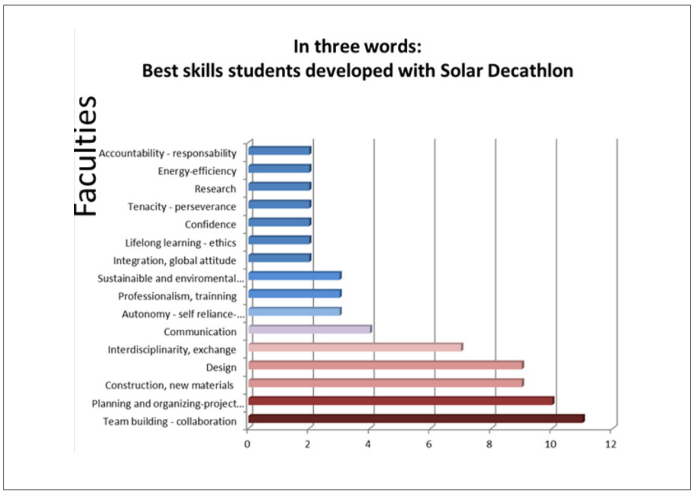



Figure 4.70: Professors answer to SDE14 Survey.

Based on the lessons learned in previous Competitions Solar Decathlon Europe is in a process of continuously self-improvement. As regards education Solar Decathlon 2021 has implemented the evaluation of the effects of Solar Decathlon Europe in the student's education. With the aim of stimulating the educational impact on the participating universities, the Team's faculty advisors need to report issues such as how is the participation in the Solar Decathlon Europe has been strategically integrated into the curricula or how are urban transformation topics have been integrated into research and teaching. A guide for a communication report applied to the specific is proposed in the Rules and Regulations.

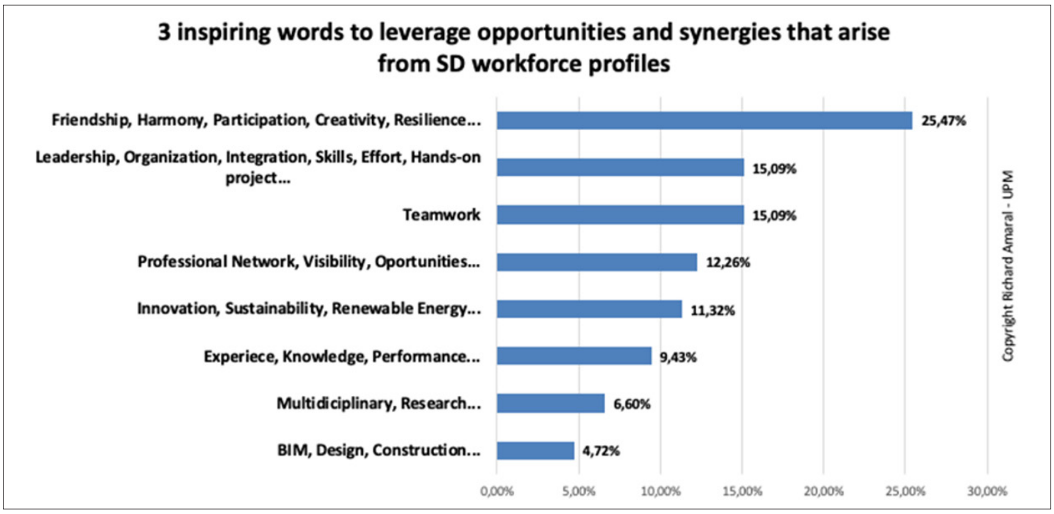



Figure 4.71: SDE20 Survey.

solar
decathlon
europe

### 4.3.2 Empowerment synergies from industrial participation

Solar Decathlon has brought university and industry together to demonstrate that Solar Buildings are a reality. First editions had their focus on the demonstration of market ready solar technology solutions to society and nowadays, the focus has been extended to achieving sustainable cities.

Synergies among Solar Decathlon Europe and industrial participation is the basis of Solar Decathlon Europe. Team funding is possible due to the collaboration between university, public sector, and industry. This collaboration enables the participation of the Teams, carrying innovative technologies further along the innovation cycle to bring them to the market. The feedback from industry after being part of Solar Decathlon Europe is very positive. Companies found profitable sponsoring both, Teams and SDE Organisation as shown in figure 4.72. 75% of them affirm that would sponsor the Solar Decathlon Europe again (figures 4.73).

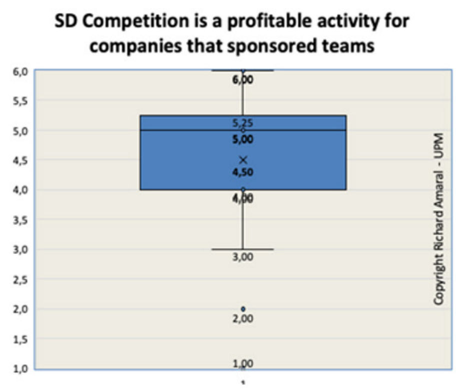



Figure 4.72: Sponsors answer. SDE20 Survey.

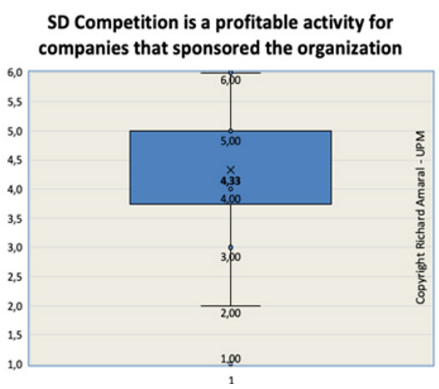



Figure 4.73: Sponsors answer. SDE20 Survey.

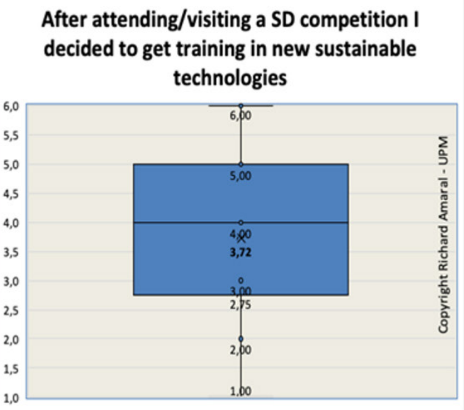



Figure 4.74: Sponsors answer. SDE20 Survey.

Companies and professionals are invited to score from 1 to 6 if after visiting the SDE Competition they decided to instigate training in new sustainable technologies, the average score is 3.72 which implies there is an input of SDE in the improvement of sponsors and professionals (figure 4.74).

Joint or coordinated efforts to achieve greater impact and efficiency can clearly be identified between Solar Decathlon Europe and industry as amplifying the communication strategies and the research and innovation impact or combining different forms of innovation and knowledge. Nevertheless, synergies in obtaining greater impacts in the training and competitiveness of Decathletes are still latent and not so clearly manifested as a general result of the collaboration between university and industry in most of the Teams.

solar
decathlon
europe

Solar Decathlon Europe accumulates young talent from the whole world and from many disciplines. Sponsors are aware of it, some of them are quite impressed with the Competition results. Not only with the houses and technology demonstrated but also with the idealism, spirit of collaboration and teamwork, the energy of students and professors is perceived, felt, and spread. Relationships and even friendships are established, in many cases they lead to the employment of students by the sponsors.

In green building design, an architecture or engineering degree per se does not make a big difference between jobseekers but those architects or engineers who have participated in the Solar Decathlon Europe are more prepared to face the challenges of innovation. Employers are expected to rate this experience as positive which should facilitate the employability of Solar Decathlon Europe students. Companies with an innovative spirit look for young talent to train it, for this they need to get close to the university, Solar Decathlon Europe accelerates and facilitates this connection.

In the SDE 2020 Survey, to the question "Would you prefer to contract a student participant in a Solar Decathlon Competition?" 100% answered they would prefer to do so and to the question "Do you think Solar Decathlon participation improves student employability?" 100% also answered positively. These statements from professionals are far from the perception of the students of whom 55% considered that the goal of fostering students' employability was not achieved.

The perception of students, professors, and professionals as to how SDE has developed students' experience in different items is compared in figures 4.69.and 4.70. All of them agree that the main aspect to value is Team working, professionals especially emphasize it. Communication is the second item ranked for all of them as valuable. Apart from these two items in which there is a relative coincidence in the responses then a variation in the different perceptions can be observed. Students value their experience in management, leadership, and friendship. Professors value student experience in management, leadership, sharing with other cultures and networking. Professionals value student experience in sharing with other cultures, risk management and resilience.


Figure 4.75


Figure 4.76

Figure 4.75: Teams in SDE12.

Figure 4.76: Saint - Gobain House.

The success of the Solar Decathlon Europe Competition is largely due to the commitment of the Solar Decathlon Europe organisers, the University Team members (professors and students), the industrial partner and the public institutions. The motives and interests behind this important commitment are diverse and mainly based on a specific result expectation.

The motivation of the students to participate in Solar Decathlon Europe are probably different, they can be related to a variety of areas of interest around the project, but a common driver could be the interest on being part of a project that aims at the necessary improvement of today's world. This ambitious goal makes the students efficient, creative, and productive.

solar decathlon europe

When it comes to building a successful Team, commitment makes all the difference. Solar decathlon Europe requires a highly committed Team, with high motivation. Students showcase engagement by heading up activities outside their comfort zone, leading a volunteering initiative, actively seeking out ways to improve their performance, working long days, etc.

To count on a committed workforce, industrial interests and society interests must be aligned. The students who have committed themselves to the Solar Decathlon are more likely to commit themselves again when the goal is linked to a common good. Once Solar Decathlon Europe has finished students have gained knowledge, abilities, and expertise, and more importantly, they have gained resilience. As a result of the changing needs they have gone beyond what was expected of them and they have demonstrated their commitment. They have gone beyond limits, sometimes self-imposed, realizing that it is possible and rewarding to strive to achieve great challenges. Most of them would commit themselves again to projects aiming at a better society. The challenge after each Solar Decathlon Europe Competition edition has finished is to be able to exploit these ‘needed’ workforce profiles to face future crises.

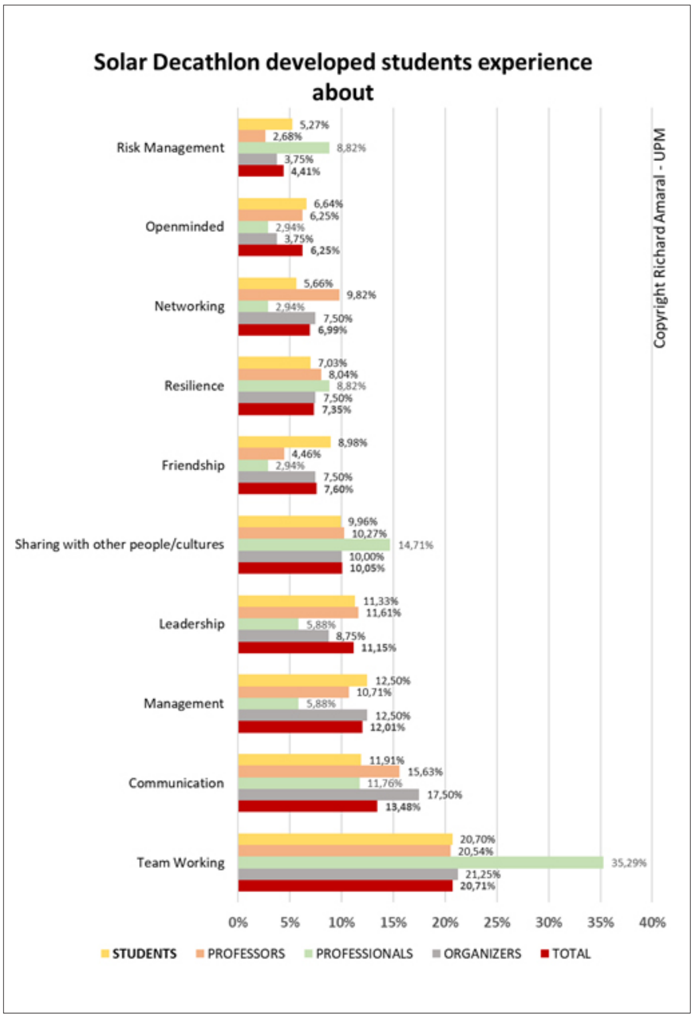
A more stable and fluid continuity between editions would guarantee a long- and medium-term involvement of industry. The continuity between European editions has been uneven; in Solar Decathlon Europe 2010 and 2012 there was continuity because the organisation team was the same, since then, from one organisation to the next there has been a transfer of information and lessons learned, but an overall transfer of knowledge in all areas has not been achieved. To remedy this, a professionalization and continuity of the Solar Decathlon Organisation team would be advisable.

To maximize impact and efficiency in this matter, in order to achieve such an interesting synergy as a coordinated university-industrial training, the Solar Decathlon Europe and the industry should have a medium to long-term perspective strategic approach, a wider approach integrating all layers of stakeholders at a regional, national and European level. To achieve this, it is crucial to align strategies and define common roadmaps but to do so, Solar Decathlon Europe needs to provide a stable and permanent setting ensuring a perspective of continuity, it needs to be supported in a medium to long-term approach.

### 4.3.3 Improving workforce & practical job skills

Solar Decathlon students and professors develop job skill needed for the achievement of a decarbonized society. Architects and engineers learn to use procedures and tools to design aiming to transform our cities towards sustainable cities. They learn about innovative technologies, implementing them, testing them, quantifying its costs, and communicating them to the user. Students from other disciplines learn about technology and sustainability linking it to marketing, design, physics. The whole experience is based on practical learning.

solar
decathlon
europe



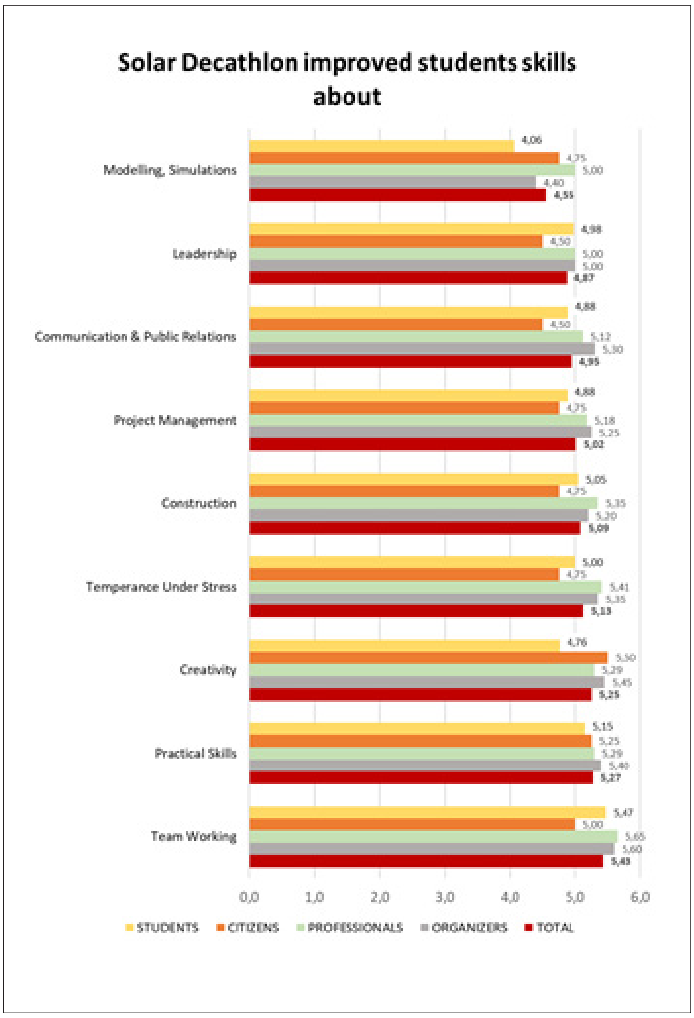




Figure 4.77: Students answer. SDE20 Survey.

Figure 4.78: Students answer. SDE20 Survey

Solar Decathlon Europe is a very ambitious project in terms of the infrastructure it requires and the means it deploys, its objectives are largely covered in each edition. However, there are items that, without being a specifically proposed objective, are results obtained collaterally, such as the workforce and practical job skills. Paying them more attention and placing them as main objectives would result in a greater impact for society without implying a greater investment.

The perception of students, professors, and professionals as to how SDE has improved the students' skills in different areas is compared in Figure 4.78. A list of skills selected from the results of the survey conducted in the SDE14 was proposed to the respondents.
From these topics, respondents had to select four skills. The professionals perception as to the impact of SDE in the improvement of student skills is in general higher than the students or professors perception, valuing aspects like team working and temperance under stress more positively. Students value creativity and the acquirement of practical skills more positively.

A university-industry partnership on a medium to long-term basis would provide a combination of private and public funding to develop specific solutions for sustainable cities and could have Solar Decathlon Europe as the spearhead of testing, prototyping and communicating new technical and social ideas, aiming to increase the competitiveness of Solar Decathlon students in European industry. Cooperation between research and education institutes and industry is inherent to the specialization and practical approach and can help to improve the workforce and skills levels in Europe.

This cooperation could lead to new forms of practical education focus on the specific challenges Europe is facing and with a view to better targeting the education and training supply to the need for skills, which can be crucial for the success of the transformation of our cities.

Figure 4.79: OTO Team in SDE12

The international feature of Solar Decathlon Europe makes it a good platform to support the internationalization of human resources in workforce and practical job skills. A network of Solar Decathlon participants already exists and with support, specific programs could be designed to coordinate research results with the industry needs to ease the process of transforming our cities into sustainable cities. The Solar Decathlon Europe network should attract innovation talents including the training in practical and entrepreneurial skills among its priorities by providing the professionals our society needs to achieve the transformation. Solar Decathlon Europe is an attractive project for innovation talents, which include among their priorities, the implementation mechanisms, the development of post-graduate courses, entrepreneurial skills, and other training practical activities.

Common methodologies between European countries are needed, encourage researcher and student's mobility, aiming to create a network of skilled workers providing the qualities needed for the aforementioned the transformation. Solar Decathlon houses can be crystallization points for the testing of common protocols. The Solar Decathlon Platform would be a useful tool to amplify or make further use of Solar Decathlon Houses to achieve a durable education and research impact on innovation and sustainable building.

solar decathlon europe

Technology is often not enough to provide successful innovation links to a real transformation. Even though the Global Challenges are common to all the European Countries, the possibilities for tackling them are very different in the European territory. Solar Decathlon Europe can serve to highlight the differences present in Europe, which are the source of our strength and weakness, leading cooperation among countries and regions in terms of research, education, creative thinking and entrepreneurial skills reinforcing the transformation capacity of the Member States and the Union.

#### 4.3.4 Leveraged opportunities

In 2010, in the first Solar Decathlon Europe, innovative technologies and systems were ready, networking between industry and university had been created but there was not yet a critical social mass demanding these solutions. At that moment, the Solar Decathlon was ahead of the market needs. Nowadays, building regulations support the use of renewable and nearly zero energy buildings. It is no longer a choice but an obligation to build nearly zero energy houses. Opportunities shall increase by promoting Solar Decathlon Europe synergies and cooperation among, higher education, research, and innovation of the highest standards, including by fostering entrepreneurship. Integrating all stakeholder's creativity to face the Competition will leverage all kinds of opportunities, since opportunities on many occasions arise from adversity, in that matter the Solar Decathlon Teams overcome multiple difficulties before reaching the final phase and during the Competition itself.

Figure 4.80: Saint - Gobain House.

Opportunities can arise spontaneously or be encouraged by intervening stakeholders, a key driver in fostering the leveraging of opportunities is to prioritize interests and enhance those aspects of greater general interest.

Figure 4.81: SDE14 Teams (SDE14 website)

Some clear and relevant items to enhance are education, innovation, research infrastructures, promote partnerships, transfer of knowledge, dissemination activities, use of the houses after the Competition, involvement of industrial associations, research into Solar Decathlon houses (international/national/regional), the connection of disciplines and trans-territorial connection. Solar decathlon Europe is a very attractive showcase that can be shared by university, industry, policy makers and many other potential stakeholders that until now have not had a relevant involvement. The traditional sponsors of Solar Decathlon are building materials and products and equipment manufacturers, an effort should be made to broaden the focus towards promoters, who have not yet found a relevant role and are closer to the user and the final product, having more reliable knowledge of what society is demanding.

Specific sectors close to the final user could be involved, such as the tourism sector, which may find in Solar Decathlon houses a differentiating factor to attract customers or other innovative accommodation solutions such as co-living models bringing together a social network which can benefit many groups, particularly those more likely to experience loneliness such as older people, or newcomers to a city.

Problems must be addressed by all stakeholders together, everyone must be linked to Solar Decathlon Europe from the beginning, join forces, be generous and generate mutual learning. Solar Decathlon Europe generates a suitable environment for this, it is an excellent setting for opportunities regarding all the aforementioned items and through further items which will emerge naturally by searching for opportunity though adversity. Having specialists and tools to support the process, the opportunities and their use will be greater.

# 4.4 benefiting from second life of sde houses after the competition

Figure 4.82: SDE12.

This section aims to show an overall vision of the great casuistry that occurs among the universities that have participated in the SDE. In practically all of them there is 'life after the Competition', in some cases the post Competition impact can be reduced to several publications but in most cases the post Competition impact is greater than the Competition phase impact. Some universities have reassembled the houses and some others haven not, regardless of it, Solar Decathlon Europe is a very intense experience for students and professors alike. In most of the cases Teams are strongly united after the Competition and some of its members continue working and collaborating.

Beyond the Teams themselves links are also established at the same university between different departments, between different universities in the same city, in the same country or in different countries, between the Teams and the SDE organisers, and also, links with industry and with other institutions. All these links are created based in this intense experience. After the Competition universities, institutions and professionals in many cases work again in common projects, some of the projects after the Competition are linked to experiences using the Solar Decathlon houses, some are not. This section focuses on the use made of the SDE houses after the Competition.

## 4.4.1 Post-Competition uses of SDE houses.

In the SDE 2020 Survey there are some questions regarding Life after the use of the house in the Competition. Figure 4.83 shows that the main life after Competition use of the houses is for educational and research purposes. 64% of the surveyors have developed educational initiatives linked to the prototypes (figure 4.84).

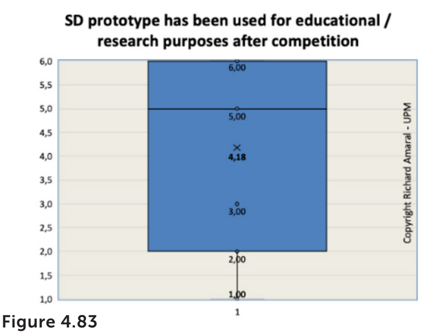



Figure 4.83

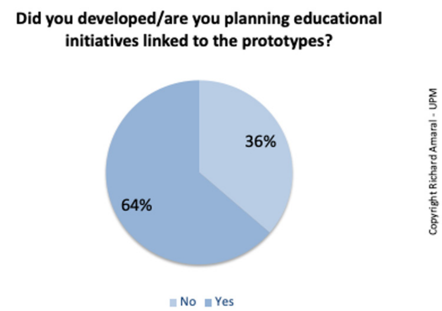



Figure 4.84

Figure 4.83: SDE20 Survey.

Figure 4.84: SDE20 Survey.

Faculty advisors answer the main use of the houses is as a living lab for research (18.24%) followed by a living lab for visitors awareness (15.72%) and as a living lab for education (13.21%), as shown in figure 4.85. This answer coincides with the use that theoretically would be advisable to give to the houses according to the faculty advisors, which is living lab for research (19.20%) followed by living lab for visitor awareness (18.30%) and a living lab for education (17.86%), as shown in Figure 4.86.

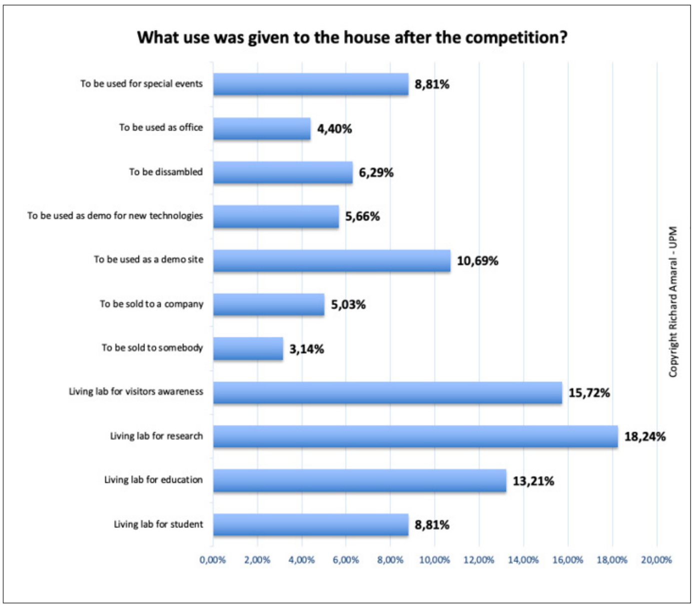



Figure 4.85: Professors answers SDE10 Survey.

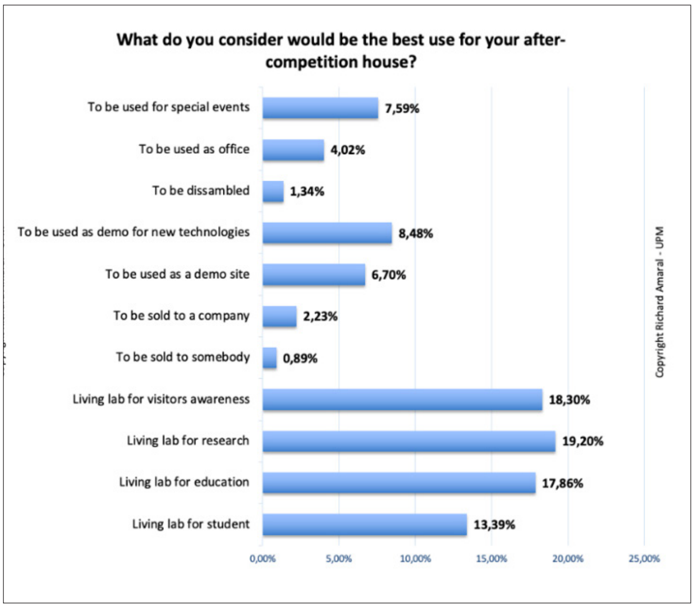



Figure 4.86: Professors answers SDE10 Survey.

However, when asking professionals what use would be the best use for the houses after the Competition, there is a noticeable variation in the answers compared to that of the faculty advisor, which is more consistent with the actual use of the houses after the Competition. The professionals opinion is that the most appropriate use of the houses is as living lab for educational use (41.18%) and living lab for research (29.41%).

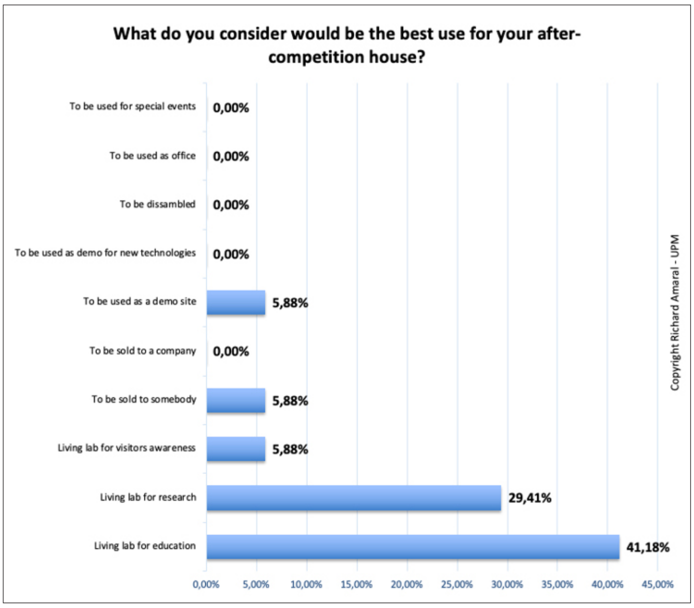



Figure 4.87: Professionals answers SDE10 Survey.

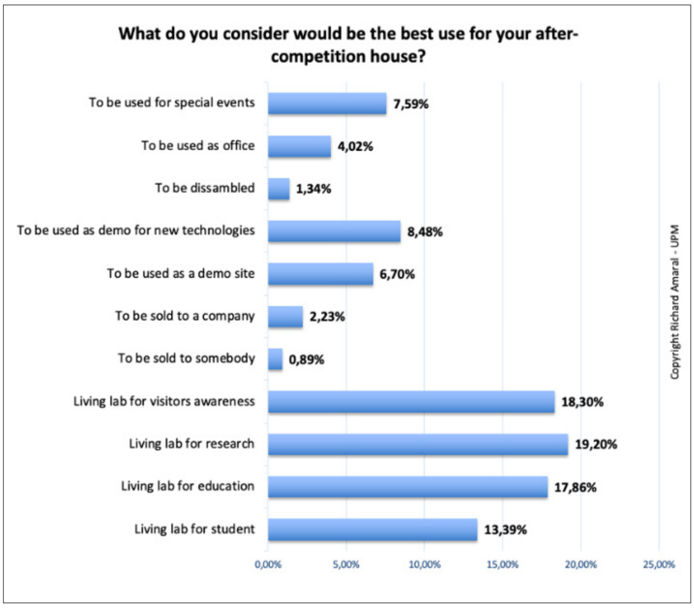
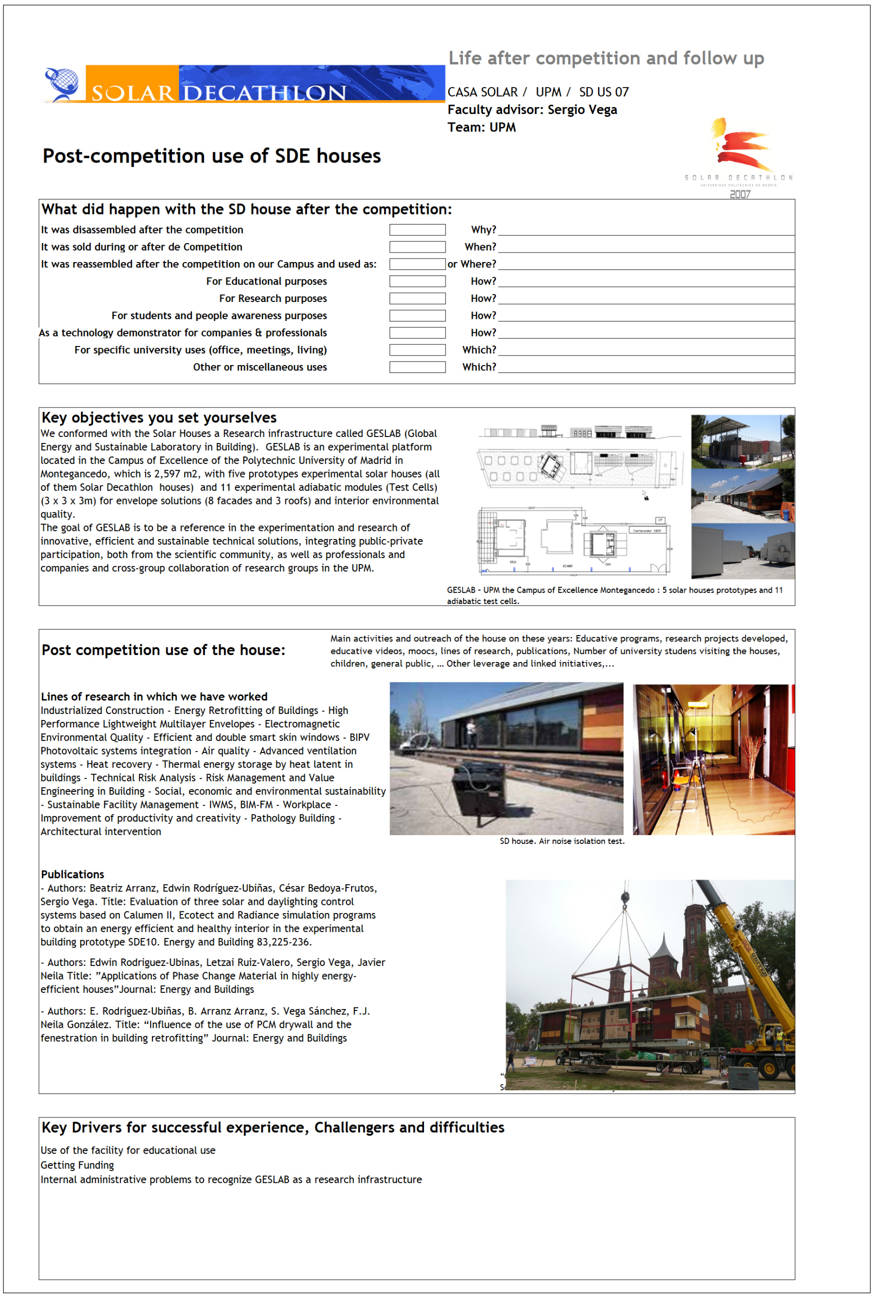



Figure 4.88: Professors answers SDE10 Survey.

solar
decathlon
europe

The following chart (figure 4.89) has been distributed to the SDE faculty advisors, most the houses are now located around the world and continue to serve numerous research projects. Some are being monitored and occupied used as living labs. Among others, the main houses use after the SDE Competitions are:

- Used as a living lab for educational and research purposes.
- For dissemination and awareness purposes.
- Used as showrooms for technologies, systems, and devices.



SOLAR DECATHLON

Life after competition and follow up

CASA SOLAR / UPM / SD US 07
Faculty advisor: Sergio Vega
Team: UPM

SOLAR DECATHLON 2007

**Post-competition use of SDE houses**

**What did happen with the SD house after the competition:**

| | | |
|---|---|---|
| It was disassembled after the competition | | Why? |
| It was sold during or after de Competition | | When? |
| It was reassembled after the competition on our Campus and used as: | | or Where? |
| For Educational purposes | | How? |
| For Research purposes | | How? |
| For students and people awareness purposes | | How? |
| As a technology demonstrator for companies & professionals | | How? |
| For specific university uses (office, meetings, living) | | Which? |
| Other or miscellaneous uses | | Which? |

**Key objectives you set yourselves**

We conformed with the Solar Houses a Research infrastructure called GESLAB (Global Energy and Sustainable Laboratory in Building). GESLAB is an experimental platform located in the Campus of Excellence of the Polytechnic University of Madrid in Montegancedo, which is 2,597 m2, with five prototypes experimental solar houses (all of them Solar Decathlon houses) and 11 experimental adiabatic modules (Test Cells) (3 x 3 x 3m) for envelope solutions (8 facades and 3 roofs) and interior environmental quality.
The goal of GESLAB is to be a reference in the experimentation and research of innovative, efficient and sustainable technical solutions, integrating public-private participation, both from the scientific community, as well as professionals and companies and cross-group collaboration of research groups in the UPM.

GESLAB - UPM the Campus of Excellence Montegancedo : 5 solar houses prototypes and 11 adiabatic test cells.

**Post competition use of the house:**

Main activities and outreach of the house on these years: Educative programs, research projects developed, educative videos, moocs, lines of research, publications, Number of university studens visiting the houses, children, general public, … Other leverage and linked initiatives,…

**Lines of research in which we have worked**
Industrialized Construction - Energy Retrofitting of Buildings - High Performance Lightweight Multilayer Envelopes - Electromagnetic Environmental Quality - Efficient and double smart skin windows - BIPV Photovoltaic systems integration - Air quality - Advanced ventilation systems - Heat recovery - Thermal energy storage by heat latent in buildings - Technical Risk Analysis - Risk Management and Value Engineering in Building - Social, economic and environmental sustainability - Sustainable Facility Management - IWMS, BIM-FM - Workplace - Improvement of productivity and creativity - Pathology Building - Architectural intervention

SD house. Air noise isolation test.

**Publications**
- Authors: Beatriz Arranz, Edwin Rodríguez-Ubiñas, César Bedoya-Frutos, Sergio Vega. Title: Evaluation of three solar and daylighting control systems based on Calumen II, Ecotect and Radiance simulation programs to obtain an energy efficient and healthy interior in the experimental building prototype SDE10. Energy and Building 83,225-236.
- Authors: Edwin Rodriguez-Ubinas, Letzai Ruiz-Valero, Sergio Vega, Javier Neila Title: "Applications of Phase Change Material in highly energy-efficient houses"Journal: Energy and Buildings
- Authors: E. Rodriguez-Ubiñas, B. Arranz Arranz, S. Vega Sánchez, F.J. Neila González. Title: "Influence of the use of PCM drywall and the fenestration in building retrofitting" Journal: Energy and Buildings

**Key Drivers for successful experience, Challengers and difficulties**

Use of the facility for educational use
Getting Funding
Internal administrative problems to recognize GESLAB as a research infrastructure

Figure 4.89: Chart distributed to SDE Faculty advisors.

solar
decathlon
europe

The main educational activities of the after-Competition phase are:

- Houses are used as demonstration projects for different subjects in Undergraduate and master's degree lectures providing cross disciplinary teaching: sustainable building design, building technologies, building industrialization, co-creation and innovation activities.
- Educational guided visits and explorative activities for university students and professional courses.
- Houses are used as meeting spaces for project development and the networking of student initiatives.
- Educational materials are created: educational videos, moocs, publications, etc.
- Houses support temporary bottom-up initiatives and projects as well as temporary working or exposition space for collaborating companies.
- Houses are used as classrooms and places to study.

Houses have been used for dissemination and awareness purposes participating in regional, national and European social awareness activities, promoting guided tours for visitors. Houses have also travelled bringing research and the academic world closer to cities and neighbourhoods. Other houses have been assembled in neighbourhoods and are being used for social research, also generating social awareness.

The main research objectives of the after-Competition phase are focus on:

- **Building performance:** Monitoring and improving houses performance, the variables are related to indoor climate, indoor environment quality, energy production and consumption, to evaluate the degree of energy self-sufficiency and the overall energy balance.
- **Building materials and systems:** Houses in many universities are used as test beds for house facilities, solar technologies, insulation materials, eco materials and smart materials testing.
- **User behaviour:** Houses are used as living labs to carry out monitoring under realistic conditions and use of the houses, mainly to understand user behaviour and to be able to reduce the gap between simulations and real energy consumption. Some designs encourage social innovation, stimulating new relationships within the community. Incorporating into the transformation of the great potential of increasing sociability in the neighbourhoods.

Some of the specific research lines developed in the houses, which aim to reduce embodied energies and carbon emissions in the construction process focusing on technology and social challenges are:

- Industrialized building construction.
- High performance lightweight multilayer envelopes.
- Smart and circular materials.
- Efficient and smart windows and smart solar control devices.
- BIPV systems integration.
- Sustainable facility management.
- Urban, energy and social retrofitting.
- Advanced ventilation systems, heat recovery.
- Thermal energy storage through heat latent in buildings.

solar
decathlon
europe

- Combination of best of traditional technics with the best of high technology and cutting-edge science to produce affordable housing.
- Indoor environmental quality: acoustic comfort, daylighting, hydrothermal comfort, air quality, electromagnetic environmental quality.
- Social, economic, and environmental sustainability: human behavior in a domestic context, change your domestic habits. House occupation and user center research experiments.
- Improvement in productivity and creativity.
- Neighborhood equipment's: co-responsibility and shared management.
- To design, introduce and evaluate experience-based, participatory learning methodologies.

Other situations different from educational use and research are related to the private sector: some houses have been sold to private owners to be used as a house or a hotel and to industry research collaborators to be used as green building design, solar energy and building technology demonstrators.

### 4.4.2 Successful educational outreach

In this section, the Escola Tècnica Superior d'Arquitectura del Vallès, Universitat Politècnica de Catalunya (ETSAV-UPC) has been selected as the most representative case in terms of educational achievement of Solar Decathlon Europe. ETSAV-UPC has participated in all four editions of Solar Decathlon Europe carried out to date: Low3, (e)CO, Ressò and TO, it is the only university that has participated in all 4 SDE Competitions.


**LOW3 / SDE10**

**Faculty advisor: Torsten Masseck**

Net Zero Energy Building based on 3 principles: low energy consumption, low environmental impact, and low economic cost. 100 students and participated on the project, obtaining the first prize in the architectural contest.

www.livinglab-low3@blogspot.com

www.low3.upc.edu

http://www.etsav.upc.edu/unitats/cisol/docencia_eng.html

**(E)CO / SDE12**

**Faculty advisor: arqbag**

The (e)co space is defined as an exchange and meeting space for the neighbourhood of Les Planes and its operation is based on the co-responsibility of all the agents involved in the project. It is a point of participation where cultural, educational, social, and productive activity is promoted. The aim is to create a space for experimentation and shared learning.

http://espaiecosantcugat.cat/

https://www.arqbag.coop/espai-eco

solar
decathlon
europe

### RESSÒ HOUSE /TEAM RESSÒ / SDE14

**Faculty advisor: Albert Cuchí & Víctor Seguí**
Team: 45 Students (Team Leader Martí Obiols Galí)
Strategy of urban, social, and energetic rehabilitation. It has the objective of creating a meeting point to promote collectivization and offer a free and comfortable space for the neighbours.
http://www.resso.upc.edu/eng/downloads.html

### TO HOUSE /TEAM TO / UPC / SDE19

**Faculty advisor: Martí Obiols & Torsten Masseck**
Team: 45 Students (Team Leader Jaume Ribas)
The project Is based on the research and analysis of the uses and evolution of activities that have traditionally been turned into a house and how progressively they have been breaking apart and extending across the city.
http://www.to.upc.edu/

Since its first participation, ETSAV-UPC has had an innovative approach in relation to the work methodology during the Competition period and to educational exploitation after the Competition. All four houses have been reassembled after the Competitions and are linked to innovative educational exploitation plans. Research projects related to educational innovation processes are also being developed.

Due to ETSAV-UPC participation in the Solar Decathlon Europe editions, the management of the school has taken the opportunity to evolve the educational system in order to promote a learning method based on cooperation and participation, less theoretical and closer to a 'Learning by doing' system. The purpose is to break with the current subject system to move to another one based on real projects. This approach aims to promote the exchange of knowledge between students of different courses and different specialities.

**LOW3 House** (SDE10) is currently a living lab at the Sant Cugat Campus. Living lab LOW3 fosters teaching and research activities in the field of solar architecture, building simulation and the scientific performance evaluation of buildings.

LOW 3 is part of CISOL (Centre d'Investigació Solar), which serves as a centre for information, exposition and documentation as regards solar technologies and renewable energies in buildings for students as well as for architects. Within regular and elective classes at the Vallès School of Architecture (ETSAV), students are introduced to solar design, solar technologies, and energy efficiency in buildings, from bioclimatic concepts up to high-tech architecture. The LOW3 project introduces new concepts of participatory teaching and an experimental building site for the evaluation of prototypes into the Sant Cugat Campus.

solar
decathlon
europe

The main educational objectives of LOW3 project are:

- To convert the LOW3 prototype into a Living Lab as an experimental platform for teaching and learning about sustainable architecture, sustainable lifestyle and ESD in general.
- To foster education in sustainable architecture, energy efficiency and renewable energies.
- To design, introduce and evaluate experience-based, participatory learning methodologies, strategies and tools regarding ESD (Education for Sustainable Development) at the campus of a school of architecture.


Figure 4.90: Educational activities in LOW E. (Source: CISOL)

LOW3 is also used for research linked with innovation educative strategies:

- It is a platform for collaborative and participatory learning activities regarding ESD in general focusing on sustainable architecture and lifestyle.
- It is a temporary supporting infrastructure for bottom-up initiatives and projects as well as temporary working or exhibition space for collaborating companies.
- It is use as meeting space for project development and networking of student initiatives. Users as drivers for teaching, research, and innovation activities: PhD students, postgraduate students, undergraduate students, external visitors (scholars, citizens, professionals)
- Users as house occupants allow user-centred research, giving feedback on concept, systems and products (Live-at-LOW3 Experiment 2012).

**(e)co** is the house from ETSAV in SDE12. The project's main objective is the search for sustainability, not only from the architectonic point of view, but also in society and the economy. It is currently being used as a meeting point and equipment of a self-managed neighbourhood in Les Planes, near the ETSAV campus.

The espai (e)co facilitates a meeting space and promotes a collaborative participation with the local community. It is a space of cocreation, experimentation and knowledge sharing. Programming and activities establish links between community members that promote self-help and reflection. Its operation is based on the co-responsibility of all the agents involved and the shared management between the city government and community. The workshops are centred on four thematic areas: research-action, co-manufacturing, sociocultural, local/environmental.

The main educational objectives of the (e)co project are to:

- Encourage social innovation. Stimulate new relationships within the community.
- Promote new dynamics of exchange of goods and services between citizens, entities, universities and companies.
- Bring research and the academic world closer to the needs of the neighbourhood.
- Spread a new life model based on energy self-sufficiency.
- Moderate and promote the management and work commission.
- Activate a process of transformation of an underutilized environment but with a great potential for sociability in the neighbourhood.

Figure 4.91: Educational Activities at e(co). Source

solar
decathlon
europe

**RESSÒ** (SDE14) is a strategy of urban, social and energetic rehabilitation. It has the objective of creating a meeting point in order to promote collectivization and offering a free and comfortable space for the neighbours. The proposal explores flexibility of space. Educationally speaking, all the components can be seen with the naked eye and are adaptable, facilitating the economic point. It is currently working as a neighbourhood centre in Rubí, a city near our faculty in Sant Cugat.

RESSÒ is a teaching tool. Before starting the project, the Team found a town and citizens to work with. When they reached an agreement with people from Rubí, they started working on the prototype. So, when SDE14 was finished, the neighbours already had a place to reassembly it, with the purpose of it becoming a social house for the people. To collectivise, and to show how could they live better and be more energy efficient at home.

RESSÒ has several educational uses:

- It is a meeting point and social house in the neighborhood. They currently carry out several weekly activities such as: theatre classes, yoga, mindfulness. The community uses the building to celebrate special days: 'carnival', spring fest, popular meals.
- University classroom. Several studios have been developed using RESSÒ and its surroundings as a classroom and place to study.
- Participative Research: the RESSÒ Team together with the neighbors have been analyzing the houses in the neighborhood. Thanks to this information they have developed 3 case study houses with 3 different types of refurbishment.

Figure 4.92: Educational Activities at RESSÒ.

solar decathlon europe

**TO** (SDE19) is the last ETSAV house to participate in the Solar Decathlon Europe. The project was not mainly focused on architecture or engineering. The focus was on human behaviour in a domestic context. The project starts with the research and analysis of the evolution of the uses and activities that traditionally have taken place in a house and how progressively they have been breaking apart and spread across the city. How much water do we use daily to wash our hands, or in the shower, or cooking? How much energy needs to be pumped to use this water? How much organic waste do we generate every day? Which is the best place in our house to cook in the winter? Or to sleep in winter. If we change our domestic habits can we save energy? Water? The planet?

With the focus on human behaviour at home the building presented to the Competition attempted to turn all of the conclusions grouped in a manifest the Team produced into reality. The result is a high flexible and adaptable house that uses a variety of filters to modify the conditions of the spaces without being bound to a specific use, so these can be moved around the house according with the time of year.

The house has recently been assembled in ETSAV Campus with 3 main educational goals:

- To become a house-museum where people can learn about all their daily consumption, waste and behavior.
- To become a living lab for architecture and engineering research.
- To become a milestone in the conflictive neighborhood.

Figure 4.93: TO. SDE 19.

Because of the Covid-19 it has not been inaugurated yet. The actual location of TO-prototype, in the new Campus is a key point, for educational success, as well as relying on an agreement with Barcelona City Hall to use TO as a museum-house.

solar decathlon europe

### 4.4.3 Other rewarding university experiences with SDE houses

**Les Grands Ateliers Innovation Architecture (GAIA)** is a technical platform initiated by ENSAG (École nationale supérieure d'architecture de Grenoble) and built by the French government in Auvergne-Rhône- Alpes region, so that schools of art, of engineering and architecture can experiment with real materials and gain a better understanding of the work of all built environment role-players. Ever since its construction, several hundred experimental projects have been developed.

The GAIA is a privately-owned company. The stakeholders are the ENSAG and Saint-Etienne national school of Architecture (ENSASE). The GAIA platform is financially supported by the regional authorities and the French government through the ministry of culture support. This structure has been set up to allow public universities to be able to carry out projects together with private partners.



Figure 4.94: Armadillo Box. SDE10.

Figure 4.95: Canopea. SDE12.

The GAIA have deployed legal and administrative instruments enabling them to facilitate the funding and the management of innovative projects. It has provided sponsorship to Armadillo Box (SDE10) and to Canopea (SDE12). The houses are now reassembled in the GAIA facilities. http://www.lesgrandsateliers.org/

**Creative Energy Homes** at Nottingham University is a key resource, particularly with respect to micro-smart grids, energy storage, demand-side management, and occupants' acceptance of innovative technologies.

The seven-house development provides a living test-site for leading firms including; E.ON, David Wilson Homes, BASF, Roger Bullivant, the Mark Group, Tarmac and Saint Gobain, to work with the University to investigate the integration of energy-efficient technologies into houses. This high-profile project attracts over 3 000 visitors every year, including the Chancellor of the Exchequer, climate and housing ministers, MPs, Vice Chancellors, industry, government departments, schools and colleges.

The research findings have fed into the UK government's green deal strategy and the Nottingham community climate change strategy and have received widespread acclaim through a number of public engagement activities, reaching out to over 5 million people.

The Saint Gobain Nottingham H.O.U.S.E (SDE10) embodies wonderfully clear, spatially concise, and sustainably efficient design from concept to reality. The H.O.U.S.E stands for home optimising the use of solar energy; it adopts a cradle-to-cradle approach to 'use, reuse, recycle'.
https://www.nottingham.ac.uk/creative-energy-homes/index.aspx

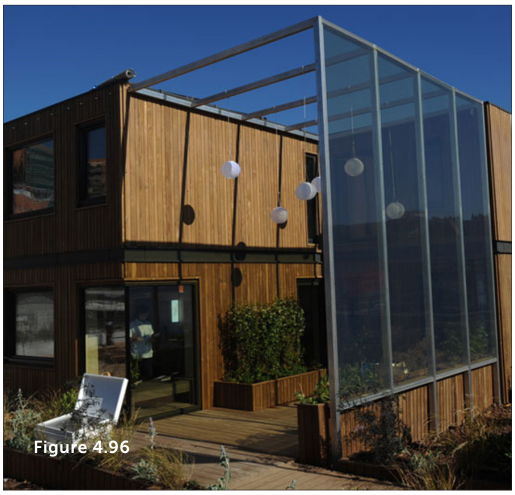


Figure 4.96

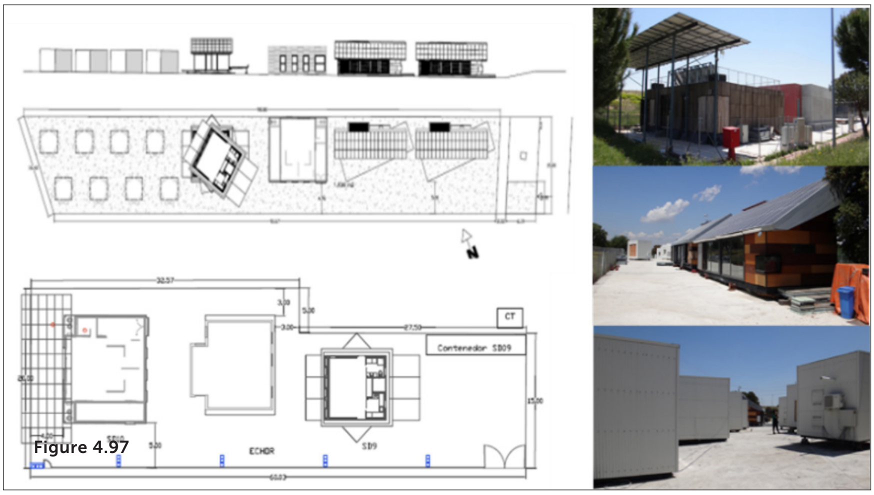


Figure 4.97

Figure 4.96: H.O.U.S.E. SDE10.

Figure 4.97: UPM SD Houses. SDUS07, SDUS09, SDE10.

**GESLAB (Global Energy and Sustainable Laboratory in Building)** at Technical University of Madrid is an experimental platform located in the campus of excellence in Montegancedo. Four prototypes of experimental solar houses (all of them Solar Decathlon houses) are located at this facility.

In GESLAB different Projects with private and public partnership has been developed. The goal of GESLAB is to boost experimentation and research in efficient and sustainable technical solutions, integrating public-private participation, both from the scientific community, as well as professionals and companies and cross-group collaboration of research groups in the UPM.

The main activities and outreach of GESLAB are: Educational programs, research projects developed, educative videos, moocs, lines of research, publications, a number of university students, children, general public, etc visiting the houses.
http://investiga.dcta.upm.es/tise/

solar decathlon europe

### 4.4.4 Exploiting solar houses in its second life

Exploiting the houses after the Competition has some mayor challenges and difficulties mainly related to the need for space and funding for the reassembly, the maintenance and operation costs and the initial exploitation costs that the Universities are not able to provide most of the time.

When it is achieved the results are optimal and there are research and educational projects developed in the houses which can lead to the self-funding. Some recommendations and suggestions extracted from successful experiences are:

- A medium to long-term exploitation plan scenario is necessary to obtain medium to long-term funding. Which can ease the way to succeed.
- From the first stages of the design phase of the houses it is advisable to work with a post Competition use and ubication in mind.
- Somehow guarantee the involvement of the Team after the Competition, it can ease the way to succeed.
- When Teams and students are involved in the management of the houses it is advisable to have a professor responsible for the project to ensure its continuity.
- Some Universities have internal administrative problems to recognize the prototypes as research infrastructure, which makes it difficult to fund research. It is advisable to work on this from the first stages of the process.
- When the prototype has been used as neighbourhood centre or a facility for educational use the maintenance and operation costs are covered, or people take care of it. People keep the prototype active and alive.
- Start with collaboration between SDE universities to conduct shared research across participants.

The Solar Decathlon Community is completely aware of these challenges and difficulties and has a general concern about the lack of optimal exploitation of the after-Life potential of the houses. This should be different, because in some cases, as shown, the exploitation is extraordinary, based sometimes on solid funding and in other cases on collective creative solutions. The last editions of Solar Decathlon around the world have approached this matter and there have been different proposals to amplify the impact of the houses longer than the Competition period.

Specifically, in Solar Decathlon Europe 2019 the Competition period was two weeks, as usual, but after the awarding event the Solar Village kept accepting visitors for two months.
This extended exhibition period made it possible for the wider public to visit the prototypes as well as facilitating the monitoring of the technical performance of the houses for a longer period than usual. After the scheduled two months the Solar Villa continued as a pilot experience for the next National Sample House Park demonstrator. To date It has been open to visits from schools, professionals and the general public with around 5 000 people visiting it. The Teams offered to sell their houses to leave them in the Solar Village. The purchase process is currently underway for the following houses: EAL - Habiter2030, GHU - Mobble, TUB - Over4, UOM - Hungarian Nest+, BME - koeb. The houses will be at the National Sample House Park, which the SDE19 Organisers are planning to open in the second half of 2020.

solar
decathlon
europe

The SDE21 Organisers have developed a living lab concept to stimulate common research activities and awareness. Teams have the choice of disassembling and removing the House directly after the event or to keep it on the solar campus in Wuppertal for permanent use. The intended use is as a living lab for learning and research and a place for public debate and workshops about topics of sustainable building and living in the city, depending on the number of houses kept on the campus after the event phase. The SDE21 Organisers set the goal to keep up to 8 houses on the site. The house and its measurement data and will be maintained and accessible, and will be part of a permanent solar village, or campus, thus raising awareness, drawing further attention, and stimulating visibility.

solar
decathlon
europe

## 4.5 conclusions & lessons learned to improve the education & training capabilities of sde competitions

Once the work described in this 'Technical Report 4: Education and Workforce Enhancements' has been concluded, and after the analysis carried out to provide insight into the real impact of Solar Decathlon Europe Competitions on the education and training capabilities of university students, we include the main findings and recommendations to improve them in this point. This analysis is mainly based on surveys and interviews conducted to assess the impact on both university students, including education, training capabilities and transversal skills & experiences, and the education and awareness of people, from children and teenagers, to professionals and the general public, about the responsible use of energy, and sustainability improvement of our buildings and cities.

The main conclusions and lessons learned from all the work carried out are:

### 4.5.1 Related to SDE educational potentials

One of the most important reasons encouraging universities to participate in a Solar Decathlon Europe Competition is the educational potential that participating in a Competition like SDE represents for the university. This potential has been widely recognized and documented throughout this report. However, it is clear from the surveys and interviews conducted that not all universities have been able to develop this potential effectively. A clear willingness, specific objectives, and an adequate strategy and planning are needed in order to optimize the educational impact in the university as a whole. It can be seen from the SDE14 survey that in most of the participating universities, official credit was given to students who participated in the Solar Decathlon Competition, which is an explicit recognition of their educational and professional training potential, but when students are asked in 2020 if Solar Decathlon is part of the university's training program and if credits are recognized for participating in the Team, only 38% of students agreed. Professors' answers suggest that in some cases they do manage them as part of the university's official programme, and in many other cases, clearly not. This is also verified by 47% of professors who intend to focus SD on learning activities, while 33% have said they will not do so, equally ratified by the students.

Beyond the educational approach that each university has given to participating Teams, with diverse and subjective perception, the greatest educational potential lies in the Competition itself and its contests, in addition to all the activities linked to the events around the Competitions. The adjustments that were made when the SD moved to Europe with the SDE10, to adapt the Competition and its contests (three completely new contests, three heavily modified contests, and the remaining partially adjusted, and with almost half of the points adapted) to European sensitivities and values, promoting education and social awareness in important and sensitive issues in Europe, have proven to be valuable from these points of view. Surveys have shown that almost all SDE contests are of interest. The four contests that have contributed most to the education of the students are engineering and construction, architecture, energy efficiency, and sustainability & circular economy.

solar
decathlon
europe

Knowledge improved mainly in the following topics: architecture and engineering integration; energy efficiency and passive design; project management; renewable energies, and practical construction.

From the Organisers of the Competitions there is also a great capacity to influence issues related to education, personal skills development, and awareness of university students. Rules & Regulations (for instance changes regarding education in the Rules of next SDE21 in Wuppertal with the intention of stimulating the educational impact on the participating universities), workshops (for example Madrid Workshop in October 2011 corresponding to the SDE12 Competition), or many different activities organised within the framework of the SDE organisation in all editions, are good evidence of this ability to influence. SDE as a whole has proved to have a high educational potential, with wide internal recognition (for instance SDE10 Proclamation, which stated the educational potential of Solar Decathlon Europe for university students, professionals and the general public), and wider external acknowledgement by the media, governments, and other public and private institutions.

The education promoted by SDE Competitions is not only limited to the acquisition of new knowledge, or to the integration of different disciplines such as architecture with structural, construction, or installation engineering, but it has a very high potential to promote educational innovation and integral education by developing personal experience, transversal skills, and professional training. This report documents SDE's high potential for educational innovation, with qualities that link it to many of the major trends known to be highly effective in terms of educational innovation: gamification, challenge-based learning and design thinking, learning by doing and hands-on experience, service-learning and experiential learning, learning in collaborative environments and team-building experience, etc. Due to the temporary nature of Competition and the lack of reflection by universities and teaching bodies, the innovative potential of SDE has not been sufficiently exploited, but there is no doubt that the possibilities of effectively improving the education and training of university students, and their university colleagues, with SDE, are amazing and we must foster and exploit them efficiently.

One of the most significant contributions of Solar Decathlon Europe from an educational point of view, is the comprehensive educational model it provides to university students, which includes not only the application of theoretical and technical knowledge of the different disciplines it covers (architecture, engineering, communication, marketing, management, etc.), often linked to innovation and research of new proposals, but also its practical hands-on application, as well as the professional training demanded by the labour market, the development of technical, management and transversal skills necessary for their work as professionals, and the enrichment of personal experience by promoting an active commitment to society.

solar
decathlon
europe

Surveys carried out in 2014 and 2020 show that 60% of both students and professors stated that they had participated in research activities during, or after the development of the SDE houses. Although 88% of students and 53% of professors stated that there were no specific professional training programs for Decathletes at the university, there is great unanimity in considering that Solar Decathlon has contributed to the development of personal skills. Practically all professors, 97%, agreed or agreed strongly with this statement, with an average rating of 4.66 out of 5, (81% in the case of students). Students highlighted communication and public relations, project management, and teamworking as main personal skills and experience enrichment. Only 16% of students stated that their university had specific exchange programmes with other universities, although it could be an important asset in the educational potential of SDE.

With the arrival of Solar Decathlon in Europe, specific objectives were defined for the first time to take advantage of SDE's media and social interest to promote educational and social awareness activities for the public. Multiple strategies were implemented, such as extending the American communication contest to social awareness, sharing this objective with the participating Teams and sponsors, developing the European 10Action project within the European Intelligent Energy program ( which allowed the investment to be leveraged to carry out activities in twelve European countries), and the main strategy of carrying out multiple activities for children, teenagers, university students, professionals, and the public in general. In this sense, it should be noted that one of the lessons learned from SDE10 was that the holding of the Competition in June, with the colleges and universities closed, did not allow for the successful organisation of activities for children and young people. Therefore, the 2012 edition of the SDE was organised in September and the Competition was extended by one week, allowing 5 000 children and adolescents who participated in our activities to visit or the 2 000 University students who made study visits during the assembly and disassembly processes. Education and social awareness of general public, of citizens, is one of the key drivers to assess the impact of a SDE Competition, and for that the preparation of a programme of attractive activities for the families, for professionals, for schools, for general public, etc. is mandatory.

Despite all the budgetary limitations suffered by all the editions of SDE so far, the social and media impact achieved with the Competitions in Europe has been very relevant, with 192 000 visitors in SDE10 and the highest media impact of the European editions; 220 000 in SDE12 with an equally high media impact; 85 000 in SDE14; and some 15 000 in SDE19, even though the Solar Villa has continued to be set up as a National Sample House Park demonstrator for many more months, open to visits from schools, professionals and the general public. In addition to this, 180 514 European citizens of all ages who have actively participated in 10ACTION activities, and have had the opportunity to reflect and learn about the responsible use of energy and how to contribute to making cities and buildings more sustainable, with a total estimated impact of 4 000 000 European citizens who have heard about these activities organised in twelve European countries by 10ACTION.

From the detailed analysis of the SDE14 surveys and that carried out for this 2020 study, there is no doubt that the main focus of the Solar Decathlon Europe university Competition has been on education and social awareness of the young university students. In scoring some of the objectives of the SD Competition, all cases averaged values of more than four out of six, with a variability of these averages of between 3.98 and 4.88, which represents a reasonable perception of the fulfilment of these objectives, taking into account the different performance of the various editions of SDE as a whole. Environmental and sustainability awareness, and fostering education, are the most appreciated. It is remarkable that in the 2020 survey 100% of the people surveyed stated that they consider Solar Decathlon to be a positive overall experience. Asked later about what is the main reason they are satisfied with SD, the overall opinion of the respondents was as follows: innovation & knowledge generation 64% (which goes up to 69% in the case of student estimation), environmental and sustainability awareness 48% (49% students), fostering education 43% (similar for students), professional awareness 40% (45% students), students employability 40% (43% students), social awareness 38% (40% students), media and social media impact 36% (39% students).

The most notable topics in which Solar Decathlon improved the awareness of students, were energy efficiency with 14.14% (of the total) and sustainability 13,64%. The contests that have contributed the most to social awareness in sustainability & energy efficiency are the energy efficiency contest with a total of 27.96%, reaching up to 40% according to the organisers, and sustainability and circular economy (20.85%). All contests show a greater or lesser influence on both the media impact and social awareness, as well as on sustainability and energy awareness. All of the skills selected were highly valued by all of the people surveyed, with measured values ranging from 4.55 points out of 6 in the lowest case to 5.43 points in the best valued case. The top ranking of these values were team working with a score of 5.43 out of 6, practical skills scoring 5,27, and creativity 5,25.

### 4.5.2 Concerning the fostering of workers' skills

The core skills important in all areas of green building: adaptability to change, environmental awareness, interdisciplinary skills, cross traditional occupational boundaries, teamworking, coordination and leadership skills are empowered in Solar Decathlon Teams. These skills, particularly the soft skills are not usually included in the curricula of technical degrees.

The main value regarding technical skills is that Decathletes put into practice the theoretical knowledge acquired during their career years. There are not usually specific training activities and Solar Decathlon is not used as a training program from the universities, nevertheless practical learning occurs even though when it is not at all programmed, it being a consequence of the accomplishment of the Solar Decathlon Europe challenges, both during the time of the project and during the Competition event itself.

solar
decathlon
europe

A protocol to guide Teams to optimize this potential should be developed as follows: teamwork, multidisciplinary, collaboration, flexibility, tolerance, environmental awareness and integrating other issues needed to face the challenges of the future to enhance creative and brave thinking not only in students, but professors, professionals and the public.

Solar Decathlon Europe can be the spearhead of testing, prototyping, and communicating new technical and social ideas, aiming to increase the competitiveness of Solar Decathlon students in European industry. Cooperation between research and education institutes and industry is inherent to the specialization and practical approach and can help to improve the workforce and skills levels in Europe. Synergies among Solar Decathlon Europe and industrial participation is the basis of Solar Decathlon Europe. The feedback of the industry after being part of Solar Decathlon Europe is very positive.

In order to achieve coordinated university-industrial training, the Solar Decathlon Europe and the industry should have a medium to longterm perspective strategic approach, a wider approach integrating all layers of stakeholders at regional, national and European level. To achieve this, it is crucial to align strategies and define common roadmaps but to do that Solar Decathlon Europe needs to provide a stable and permanent setting ensuring a perspective of continuity, it needs to be supported in a medium to long-term approach.

The international feature of Solar Decathlon Europe makes it a good platform to support the internationalization of human resources in workforce and practical job skills. Solar Decathlon Europe network should attract innovation talents including, among its priorities, training in practical and entrepreneurial skills, thus providing the professionals our society needs to achieve the aforementioned transformation.

Opportunities shall increase by promoting Solar Decathlon Europe synergies and cooperation among, higher education, research, and innovation of the highest standards, including by fostering entrepreneurship. Integrating all stakeholder creativity to face the Competition will leverage all kinds of opportunities, since opportunities on many occasions arise from adversity, in that matter Solar Decathlon Teams overcome multiple difficulties before reaching the final phase and during the Competition itself.

Some clear and relevant items to enhance are education, innovation, research infrastructures, promote partnerships, transfer of knowledge, dissemination activities, use of the houses after the Competition, involvement of industrial associations, research into Solar Decathlon houses (international/national/regional), the connection of disciplines and trans-territorial connections.

Problems must be addressed by all stakeholders together; everyone must be linked to Solar Decathlon Europe from the beginning, join forces, be generous and generate mutual learning. Solar Decathlon Europe generates a suitable environment for this, it is an excellent setting for opportunities regarding all the aforementioned items and through further items which will emerge naturally by searching for opportunity though adversity.

solar
decathlon
europe

#### 4.5.3 In relation to post-Competition & Living Labs opportunities

Exploiting the houses after the Competition has some mayor challenges and difficulties mainly related to the need for space and funding for the reassembly, maintenance and operation costs and the initial exploitation costs that the Universities are not able to provide most of the times.

Some recommendations extracted from successful experiences are:

- A medium to long-term exploitation plan scenario is necessary to obtain medium to long-term funding. Which can ease the way to succeed.
- From the first stages of the design phase of the houses it is advisable to work with a post-Competition use and location in mind.
- Somehow guarantee the involvement of the Team after the Competition, which can ease the way to succeed.
- When Teams and students are involved in the management of the houses it is advisable to have a professor responsible for the project to ensure its continuity.
- Some Universities have internal administrative problems to recognize the prototypes as research infrastructure, which makes it difficult to fund research. It is advisable to work on this from the first stages of the process.
- When the prototype has been used as neighbourhood centre or a facility for educational use the maintenance and operation costs are covered, or people take care of it. People maintain the prototype active and alive.
- Start with collaboration between SDE universities to conduct shared research across participants.

The Solar Decathlon community is completely aware of these challenges and difficulties and has a general concern about the lack of optimal exploitation of the after-Life potential of the houses. The last editions of the Solar Decathlon around the word have approached this matter and there have been different proposals to amplify the impact of the houses longer than the Competition period.

#### 4.5.4 Final Conclusions

The surveys and interviews conducted in the 2012, 2014 Competitions and 2020, clearly show the great educational and social awareness potential of the Solar Decathlon Europe Competitions and the degree of influence that the Competitions have had on all students, professors and professionals who have participated, to the extent that 100% of those surveyed consider SD to be a positive experience overall. However, the analysis of the surveys also indicates that the educational potential is not fully exploited either at the level of the participating universities or at the level of the organisers themselves, not to mention the lack of a European strategy to facilitate the exploitation of the synergies offered by the network of solar houses participating in SDE to organise activities in multiple countries, optimizing the education and social awareness of our citizens.

solar
decathlon
europe

According to the analysis carried out, the following conclusions and lessons learned can be drawn:

I **The Energy Endeavour Foundation (EEF), as promoter of Solar Decathlon in Europe, and the organisation of every SDE Competition, should encourage participating universities to plan a strategy of integral educational exploitation, and to invest in the necessary resources to maximize a comprehensive education and professional training potential, as well as the cross-disciplinary development of skills, enhancing the SDE experience. In this sense, the adjustment of the Rules & regulations for SDE21 in Wuppertal, Germany, asking for the documentation of each university's strategy to stimulate the educational impact, for its evaluation in Competition, is considered a very good initiative.**

II **The Energy Endeavour Foundation (EEF), should define strategies to encourage the use of the full potential of educational innovation that SDE has at its disposal, in order to favour the comprehensive education of university students, including the enrichment of the SDE personal experience, the development of transverse skills and the improvement in professional training with an integral education model. That educational innovation implies the will to innovate and a planning of how to implement it, supported by theory, and a continuous process of reflection and improvement. Organisers, centered in the Competition, and due to the temporary nature of Competition and the lack of continuity, have fewer opportunities to reach other European countries without the EEF guidelines and support.**

III **Universities participating in a SDE Competition must include a strategy and planning for the reuse of the houses after the Competition, with programs to exploit the full potential of the houses for educational use by the whole university, to develop research programs and projects, as well as the potential for raising awareness among university students of sustainable energy efficiency issues, and where appropriate, for raising awareness among children (schools), professionals, and the general public. The EEF could, through the 'Call for Teams', promote such a culture of planning from the beginning and the later use of the house for an educational or research use, as one of the many criteria for the selection of the Teams.**

IV **The attractiveness of a university Competition such as SDE, on its own, does not justify the huge amounts of investment it needs in terms of money and human effort, both for universities, as well as for the organising countries-cities, and sponsoring companies. Universities need to exploit the full potential of innovation, research and education for the university, both through Competition and through the subsequent use of the SDE houses, as well as through the potential for communication and social visibility that it represents.**

solar
decathlon
europe

Host countries need to take advantage of the social and environmental impact of SDE to educate and raise the awareness of their citizens, from children and young people (the future), to professionals and the general public (the present), providing a sufficient return in public image. Likewise, companies that sponsor Teams and organisations need a return in media and social visibility. Without a doubt, one of the key drivers for a successful edition of Solar Decathlon Europe is understand the Competition and the linked event (with the development of activities for the public), as a whole, to attract the maximum number of visitors and media, in order to increase sensitivity and disseminate innovations among professionals, and to educate and raise awareness among citizens.

V The challenge of attracting as many visitors as possible, can be enhanced by a good location in a central and well-intended area of the city (which it is not that easy because of the technical constraints derived from cranes and trucks of great size and tonnage), good public transport to access the area, a dissemination campaign in the city and in the media to draw attention to the event, the preparation of a program of attractive activities for the families, so that they can go with their children with some guarantee that they will have a nice time. Budgetary limitations suffered by all the editions of SDE so far, are translated into the cutting of educational and social awareness activities that are one of the keys to attracting families, schools, professionals, and educating them. In order to attract children through school visits and groups of university students for learning during the process of assembling the houses and during the Competition, it is necessary that these are held during the school year, the beginning of the academic year (September and October) it being the ideal time to maximize the organised presence of young people.

VI The harnessing of the educational and social awareness potential of SDE Competitions in EU countries is necessarily linked to a greater commitment by the European Commission to SDE, and as it has already publicly stated on more than one occasion, such as on November 28, 2011, the EU-U.S. Energy Council meeting in Washington DC, led by US Secretary of State Clinton and US Secretary of Energy Chu, EU High Representative Ashton and EU Commissioner for Energy Oettinger, which stated, among many other points, that *"The EU and the U.S. intend to cooperate on continuing the Solar Decathlon Europe Competitions, transforming them into an initiative to foster sustainable economic development by creating markets on both sides of the Atlantic for integrating innovative technologies and renewable energy sources into new and refurbished low impact buildings."* The success of the European project 10Action (Supported by Intelligent Energy Europe) has allowed 180 514 European citizens to participate in educational and social awareness activities in twelve European countries between 2010 and 2012 (3 years), with an investment that has served to leverage the work of SDE and the SDE10 Teams by taking these activities to their countries of origin. The prestigious communication award obtained by SDE in the sustainable Energy Europe Awards Competition in 2011, highlights the interest of Europe's support to these initiatives.

solar
decathlon
europe

VII The Energy Endeavour Foundation (EEF), as promoter of Solar Decathlon in Europe, should favor the formation of collaborative networks of the SDE university community (currently around 50 universities in Europe), and articulate collaborative exchange channels both for research projects and to foster initiatives that promote education and social awareness of universities and their environments, taking advantage of the potential of SDE houses. The timeframe for the organisation of an SDE Competition and the limited budget available do not allow for the planning of activities in other European countries, or for project initiatives with this approach, in the medium term. In order to take advantage of the educational and social awareness potential of the Solar Decathlon in Europe, the financial support of the European Union to the EEF is mandatory to promote this growing network of SDE universities, and to approve 10Action type projects that allow limited investments from the European Union to generate a high media and social impact, and with the commitment and complicity of SDE universities, to educate and raise awareness of millions of European citizens concerning the efficient use of energy and natural resources, and improving the energy efficiency and sustainability of our buildings and cities, some of the key aspects for achieving the 'zero carbon' challenges in Europe, and the Sustainable Development Goals (SDG).

VIII A policy of strong European support for Solar Decathlon Europe, and an active collaboration with the EEF, would allow a strategic alignment of these university Competitions with the European Union's research, education and social awareness priorities, in order to promote technological innovation, raise the awareness of European professionals, and better harness the potential from educational innovation for the training of the next generation of European architects and engineers who will build the sustainable European society of the 21st century.

# solar decathlon europe

## conclusion

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# conclusion

The four Thematic Reports have documented a remarkable evolution of Solar Decathlon Europe (SDE). It has been a decade since its first edition in Madrid[1]. After 2010, there were two more consecutive successful editions, in Madrid (SDE12) and Versailles (SDE14). After the SDE14 event in Versailles, no other country could assume the leadership of organising the next edition in Europe. This led to a group of former SDE Organisers and alumni to seek support at a European level. The result of these efforts was the establishment of the Energy Endeavour Foundation, a Netherlands-based non-profit organisation, responsible for governing the continuity of the SDE. The EEF received the endorsement of the US DOE to steward the Solar Decathlon in Europe, and made the first Call for Cities in 2017. With the designation of Szentendre, Hungary as Host City under the leadership of EMI and the Hungarian Government, the fourth edition of the SDE was held in July 2019. The next edition for the Solar Decathlon Europe is the SDE21 to be held in Wuppertal in 2022.

The immense experience accumulated in the four editions held in Europe to date is rich and varied. The multiple and systematic analyses carried out throughout this project have allowed us to bring critical reflection, to recognise the great potential of the Competition in Europe, and to draw many lessons learned, with regards to the Competition itself, and also on how to ensure continuity. By taking advantage of previous experience and maximising outreach at a European level, the SDE impact can be truly European.

To date, 65 demonstration houses have been designed, built and operated by the student Teams, and hundreds of companies have been involved. The Solar Decathlon Europe has become the most international of five non-US Solar Decathlon chapters. Universities representing 26 countries from Europe and abroad have proudly participated in intensive, interdisciplinary ‘learning by building’. Hundreds of thousands of visitors have come in close contact with innovative architecture, design, and engineering, and numerous media channels have reported intensively on the four events to date.

The SDE21 in Germany with its eighteen international Teams will take place in the spring of 2022 in response to the worldwide COVID19 pandemic[2]. The SDE23 Call for Cities has been launched by the Energy Endeavour Foundation with the intention to move forward in the evolution of the SDE[3]. The next organisers will face new challenges, some of which have been documented through the EC project *‘Solar Decathlon Europe - Analysis of the results’*. Over the past three years, this project has provided a framework to document and analyse the SDE Competitions to date.

Parallel to this, the working group ‘Competition and Living Lab Platform’ (Annex 74[4]) of the International Energy Agency’s EBC program has added to this work by focusing more on the value of the Competition format for the building science community and vice versa. One of the values of both these projects is that that the outcomes will be made available as public resources. These can assist future Organisers and Teams to benefit from the experiences and lessons learned in order to successfully prepare, realise and participate in future Competitions.

[1] https://solardecathlon.eu/sde-2010-10-year-anniversary/

[2] https://sde21.eu/new-date-solar-decathlon-europe-21-postponed-until-june-2022

[3] https://solardecathlon.eu/sde23_call-for-cities/

[4] https://building-competition.org/

solar
decathlon
europe

**Competition Challenges**
The first four SDE Competitions have revealed many strengths in the SDE format, and several challenges that future Organisers will need to address. What follows is a brief summary of the key aspects detailed in the reports themselves.

Event Site & Communication Strategy
The Solar Decathlon Europe has taken place in a European capital (Madrid, Spain), on a European historical site (Versailles, France) and also on a remote research campus by the river banks of a fluid waterway to a highly frequented tourist destination (Szentendre, Hungary). Experiences from other SD chapters in the US, China, Latin America - Caribbean, Middle East, and Africa add to the lessons learned regarding the event site. Typically, city officials are not the primary Organisers responsible for the events; this usually falls to local universities or scientific institutions.
It is the task of potential Organisers to investigate, propose and secure a site of about 20 000 m², offering a suitable infrastructure. Taking into account the enormous market pressure on attractive sites in major European cities, the challenge of finding a viable location with secure and financing during the whole process is formidable. From the Call for Cities to the final event, this spans about 2,5 years (and perhaps even longer if a post-event living lab phase is planned). The availability and financing of such a site is a major requirement to run a Competition and its Solar Village.

Without adequate communication strategies, SD Competitions held at remote sites outside city centres have seen drastically reduced numbers of visitors and the consequential impact of the event in public awareness (see SDE 19, SDME18). Whether or not in a metropolitan centre, transportation needs to be properly considered to avoid unnecessary individual vehicular traffic. Depending on the location, alternative methods of transport are desirable (e.g. special public buses, bicycle routes, etc.). Past experience has shown that before Competitions are considered outside of cities, specific outreach planning is needed in order to address not only professional audiences, but the public at large. Communication activities and parallel events on site can draw attention to the Competition and attract more visitors. Having a large number of interested visitors is a major stimulation for the Teams and is often a precondition for sponsors. Having the public present is integral to the atmosphere and spirit of the Solar Decathlon Europe and its impact on the community.

Event Frequency
The continuity of regular Competitions is a fundamental goal of the Solar Decathlon Europe community. The pause between SDE 14 and SDE19 left a huge task to the Energy Endeavour Foundation in rejuvenating the SDE with the next Organisers. The SDE19 Competition drew a decreased number of Team applications and participants. On one hand this reflects the rising number of concurrent SD events worldwide. On the other hand, it also represents a common perception that large efforts and funding are needed for successful participation. With the SDE21, the EEF has advanced the city designation process and thus the Call for Teams as well. This proved successful in SDE21 where the advanced timetable together with the profiling of the event by the organizers resulted in over twice as many Teams applying for the available eighteen positions in the Competition.

solar
decathlon
europe

It is possible to consider a different rhythm for the SDE. Although typical innovation cycles might suggest one comparable to the Olympics, in the end, ensuring an attractive Competition with sufficient participation, innovation and quality of contributions is up to the host city and the themes of that particular event. A longer cycle might improve the chance for public funding – EU, national, regional, local – both on the event level as well as the level of industry involvement with Teams. This kind of deeper support might enable smaller institutions to take part in the Competition while significant EU support might stimulate more countries to host a Competition. The viability relies on the EEF's stewardship, combined with the interest of potential local and regional parties interested in hosting the SDE.

Since 2018, the US-DOE has become more pro-active in coordinating the timetables of the international SD events, which can only help to mitigate a competition for viable international Teams amongst SD event Organisers. There appears to be no lack of enthusiasm for international participation given the rosters of current Solar Decathlon chapter events (SDUS20, SDME20, SDE21, SDC21).

### Event Profiling

Together with their funding institutions, the local SDE Organisers typically develop the general event profile. SDE21 in Germany may serve as an example. In the case of Wuppertal, profiling was done by adding a design challenge to the demonstration unit task. This fit well to the focus of Wuppertal's Competition bid. The design challenge defined as a typical urban densification task creates a real context for all of the demonstration units. In SDE21, context is a main issue to better position the Competition in the architectural debate, and it allows the consideration of adjacent urban layer aspects such as mobility. The common urban context, including the focus on further construction and use of the existing building stock reflects the main requests of the Declaration of Madrid, signed by the Team leaders after the SDE10 event. Transformation of the existing building stock towards climate neutrality is a main task in the European energy policy; the example of SDE21 underlines the chance of profiling an event to better fit into current and future needs of major stakeholders and local conditions.

All-electric homes as demonstrated in all SD Competitions to date are just one of the options to reduce climate emissions of buildings. It is a precondition that the power used is mainly based on renewables. Urban options for the transformation of the building stock to climate neutrality might be different and based on a mix of energy systems and sources such as green district heat/cold, biogas, green hydrogen etc. Future Organisers in other regions of Europe will need to align the Competition to local and regional conditions.

One issue that urbanisation brings is the affordability of living space. The focus should not lie just on technical prowess or design aesthetics, but should also demonstrate affordable solutions for the general public to fully cover the social dimension of an urban transformation to climate neutrality. The consideration and inclusion of social scenarios is strongly recommended, regardless of the context of a given SDE event.

solar
decathlon
europe

### Event Networking

The Solar Decathlon is a successful worldwide movement. A network of universities and students has been created through the events over the past two decades. The relation of the Competition to other relevant communities, stakeholders, and events outside the SD community itself can be improved. Some outreach has been made (European Sustainable Energy Week, EU Sustainable City Information System, Eurosolar, Solar World Congress, BAU, ISH, etc.). However, it still seems a major task to establish the SD Competition in the general energy policy debate, the architectural dialogue, and the major building industry associations. Broader recognition of the format and its successful networking could stimulate additional resources for the support of the SDE proliferation, SDE events, and for individual SDE Team financing. This can only help to increase the success of the fundamental SDE goal; to communicate to citizens about resource responsibility.

### Solar Village

The COVID19 pandemic has demonstrated the fragility of international travel and large public events. The SDE21 has been affected, at a minimum, through the postponement to 2022. Thus, it seems appropriate to investigate options for keeping the spirit of the SDE Solar Village, while working with scenarios that investigate scenarios involving centralised or decentralised structures and / or formats.

The effects of the COVID19 pandemic notwithstanding, the idea of a decentralised Solar Decathlon is currently under discussion. A design-build-operate event based on the Solar Decathlon format was held nationally in the Sultanate of Oman in 2014. Here each of the five universities located in and around Muscat built their houses on their own campuses, all within an hour's drive of each other. The consequences of the COVID19 pandemic in the United States has forced the Organisers to convert the SDUS20 event into a decentralised Competition. They have asked the nine participating Teams from North and South America, Europe, and Africa to build their houses locally, abandoning the original idea to assemble, or build, them together in Washington D.C.

The idea of a decentralised Competition might seem attractive at first glance. It would remove the costs and carbon footprint of transport, it would reduce the risks associated with rapid assembly in 10 days, it would allow a more thorough construction process akin to real-world practices, and it would allow the possibility for permanent structures as living-labs on the local campuses. However, this ignores the nature of the Competition as the 'America's Cup' of architectural Competitions. The SD houses are not intended to replace the products on the market, but to provide inspiration for the students, for their sponsors, for visiting professionals, and the public at large. In terms of carbon-footprint / people reached, it could be said that the Solar Decathlon format is quite efficient in its outreach and impact, transport included.

solar decathlon europe

It must also be noted that a fundamental attraction of the Competition is the atmosphere in the Solar Village. It buzzes through the combination of youthful ambition, high goals of sustainability, and the exciting challenge of competition. This is what attracts the public, practitioners, and sponsors to the Solar Village. A decentralised version of the Competition will never, even with the best of 'augmented and virtual reality technologies', come close to that. As was stated in the *Foreword*, the visitors and the media attention are what drive sponsors. In short, the Solar Decathlon is not a Solar Decathlon without the Solar Village.

A Solar Village stimulates student impetus, triggers the formidable lessons that come with learning by building in the singular SDE environment, where students build side-by-side, in situ, under healthy, collective challenges. Decathletes excel through powerful mentoring, industry feedback, scouting from potential employers, and expert jury advisory. These factors test and coach Decathlete Teams toward their best capacities and future careers.

### Design vs. Design-Build-Operate

In the United States, the SD organizers have added a 'Design Challenge' to the SD 'Build Challenge' Competition. The 'Design Challenge' (formerly known as the 'Race to Zero' Competition) was incorporated in 2018 into the Solar Decathlon management as part of a US DOE realignment. In the Design Challenge, student Teams work for one or two semesters to prepare solutions on paper for real-world issues in the building industry and present the designs to a jury.[5] Competitions like this are widespread around the world and contribute to the immense competition among competitions for students.[6]

[5] https://www.solardecathlon.gov/event/challenges-design.html
[6] https://www.europan-europe.eu/en/

The triple premise of 'design-build-operate' marks the difference of the SD Competition to other competitions and forms a unique selling point in education. Students grasp that designs must work, and learn about what it takes to make them work. Building practice all over Europe has underlined the gap between design and the real performance of buildings in terms of energy use, carbon emissions, indoor climate etc. Students of architecture and engineering learn that even great ideas need detailing to convince, and a prototype to prove a concept. Setting up and testing the demonstration units underlines that it is not the main task just to *have* a solar system, but that reducing the carbon emissions of a house in reality needs a coordinated operating the system to achieve the performance as designed.

### 'Learning by Building' & Building Science

The work within this project as well as in the IEA Annex 74 has underlined a strong need for a more structured documentation of the Competition houses. In the previous Teams' documentation, (often quite extensive), facts were sometimes cloistered, incomplete, or inconsistent. As a response to this, a template was developed in IEA Annex 74 and will be implemented in SDE21. This should allow better access to the quantitative information, which will allow better cross-documentation and analysis.

solar
decathlon
europe

To date, the analyses of the SDE energy systems have been mainly limited to the house's energy consumption and the energy yield of the solar power systems. The considerable time and expense that goes into developing and constructing the buildings raises the question of an advanced monitoring concept for subsystems such as heat pumps, thermal solar systems, ventilation systems, etc. SDE14 introduced a systematic breakdown on the consumption side.
As a result from work within Annex 74, detailed measurements for the photovoltaic systems will be on the agenda (performance ratio) in SDE21 and 'public' and 'science' days are separated consequently in order to make better sense of the monitoring results. There will, for the first time, also be a comparison of simulation and measurement on three days before the actual Competition in an attempt to measure the design-to-performance gap. This will clarify what findings can be obtained, what value they have and thus what effort and investment in monitoring are recommended for future SDE Competitions. Measurements at the component level could also stimulate industry partners to be involved in an industrial competition for components, following, or parallel to the student Competition.

Teaching and Interdisciplinary Work

Testimonials experiences at many participating SD community universities reveal that becoming a Team in a Competition can be a great resource to simulate new teaching formats that bridge disciplines. Established borders within universities can be lowered and cooperation often continues after participation in a Competition To date, the high potential of innovative teaching formats has not been fully explored and more efforts are needed to and stimulate and learn from these.

Almost all Teams have been composed of students from different faculties, such as architecture, mechanical and electrical engineering, economics, communication, social sciences, design, etc. Teams are represented by one, or many, universities from one, or many countries.
Future Competitions could further stimulate interdisciplinary work; while this policy has not been typically pursued in European higher education, it is being explored and encouraged.
A further potential is the link between academic and trade education. It is very important to communicate these aspects as a major incentive for participation in an SDE Competition.
The potential benefit on the university level is much greater than the ranking in the Competition.

Working with performance simulation tools for energy, indoor climate, lighting, life cycle assessment, circularity, etc. in the early design phase stimulates the buildings' design proposals, and avoids extra costs for adjustments in the later phases of planning and construction. The range of Competition houses reveal Teams with great know-how to others who are new to the design-build paradigm. Workshops, working documents, and common tools may be considered to raise the overall level of Competition entries. The IEA Annex 74 members have also contributed to the Building Competition Knowledge Platform with initial outcomes.[7]

[7] https://building-competition.org/

Building information modelling (BIM) also serves as the state-of-the-art format for intensive documentation and linking of information over the entire life-cycle of a building.
Future Competitions are a very suitable testing ground for BIM application and the teaching of BIM best-practices.

solar
decathlon
europe

### Living Labs

Several participating Teams operate their houses after the Competition for research and education on their own campus or nearby their home universities. An example, see the Living Lab project LOW3 in Barcelona.[8] It is a major task for each Team to secure the additional financing for infrastructure, monitoring etc. It would be desirable to connect these post-Competition labs toward the exchange in lessons learned, and to increase communication and visibility in connection with the SD community.

[8] http://livinglab-low3.blogspot.com/

Typical urban sites for the Solar Villages, as well as sites belonging to research institutions, do not usually allow continuous habitation of the demonstration houses. This needs to be addressed where potential host cities are considering a living lab phase. Having real, inhabited houses after the Competition for research and publicity might require a different format than the Solar Decathlon (i.e. industry-sponsored professionally-designed permanent housing). The need for rapid assembly, disassembly and transportability has a significant impact on the SD building design and construction, as well as a factor in their cost. Preparing a central living lab following a Competition needs early research and clarification in order to identify the final site and the compliance to local laws. For most Teams, a living lab phase is secondary to the core goal of participation in the Competition. A living lab phase could become part of a Call for Teams to ensure all Teams consider post-Competition use as part of the brief, depending on the goals of a potential Host City.

In many areas, the SDE has identified innovations in the field of energy systems. Until now, a detailed quantitative assessment has not been possible within the framework of the Competition. It remains the role of the Teams to pursue these questions after the Competition by working on their houses at their definitive locations. Many Teams have done so in the past, operating the buildings as living labs back at their universities. At the SDE19 in Hungary, and the SDA19 in Morocco, and in Dubai at SDME18, some buildings were, for the first time, able to remain on the Competition sites, as these were part of research centres' own lands. This has benefits for subsequent research. In the case of SDE19 and SDME 2018, the location was not combined with an adequate communication strategy, which had a very negative impact on visitor numbers. SDE21 has already communicated to the Teams, that eight of eighteen Teams can leave their demonstration units on the site to form an international living lab for three to five years of operation.

Another advantage of buildings remaining on the site is that it allows systematic commissioning and adjustment to achieve improved results in subsequent measurements. From the perspective of research, this is a shortcoming in the actual Competition profile, as there is not enough time for it in the Competition schedule. Unlike in practice, the houses in the Competition must function perfectly immediately after assembly. For buildings that remain in place, systematic, scientific tests can be carried out at a building level (co-heating tests) and at the component level (dynamic U-value testing, COP analysis, etc.). However, the buildings remain uninhabited, as living on test sites is usually not permitted under local building laws, so even so, the monitoring outcomes are limited.

solar
decathlon
europe

### Improving European Outreach

We are absolutely convinced that the Solar Decathlon Europe can become an effective instrument to build Europe, and to promote and support the European objectives and policies of the European sustainability agenda ('European Green Deal'). The SDE supports technological innovation, education and training of future architects and engineers, and raises awareness among citizens and professionals. Together, they can contribute to the transformation and use of our buildings and cities in a more sustainable way, helping towards a circular economy with zero carbon and zero non-renewable energy.

It is important to understand that the Solar Decathlon Europe is an effective and potential vehicle for social awareness. It is not just the Competition itself that has weight; it is the Competition with its associated events driven by a strategy to make the visitor's experience attractive, while raising awareness among youth, professionals, and the public at large. Activities are specifically designed for each target audience. However, without an adequate communication strategy and budget, based on an accessible central venue, the effectiveness of the event is underutilised. As we have seen, a Competition with a vibrant audience is most effective. A lack of visitors discourages universities, reduces the support of the administrations, minimises the possibility of sponsorship, and counters the potential of the Competition and the Solar Village.

The intensity required to effectively and properly organise the Competition and associated events, has meant that the host's communication actions have mostly been limited to the host city of the Competition, and to a lesser extent, the organising country. The consequence is that the impact across Europe is limited to the universities that participate, with reduced impact on the media, professionals, and European citizens.

It was in the second edition (SDE12) that a noticeable degree of European impact was achieved. This was done by mobilising the participating European universities in SDE10 and SDE12 to extend social awareness activities toward their respective environments, cities and citizens; the '10Action' project funded by the European Commission within its Intelligent Energy Programme helped to leverage this outreach, awareness, and impact. Dozens of activities took place across twelve European countries, in addition to Solar Village activities such as congresses, conferences, workshops, educational exhibitions for the general public, family visits, and guided tours, with material and messages of social awareness for each target group. In this sense, the synergy of the 10Action project was a key driver for the success of the first two SDE editions, and its absence was noticeable in the next two.

A lesson learned from the first four editions is that the commitment with direct and active participation of the government of the organising country, and the European Commission, resulted in the direct participation in activities of about 500,000 European citizens. As an example, in 2010 there was a visit by the Ministers of Housing of the European Union to the Solar Village, coordinated with the 10Action project. In the past two editions, the lack of wider European outreach has led to a drastic reduction in the impact outside of the host city.

solar decathlon europe

It is essential both to articulate the continuity of SDE Competitions and to take advantage of the experience of previous Competitions, taking into account that the organizers change from one edition to the next. Therefore, a mechanism or institution is needed to unite the experts who can foster this transfer of experience and continuous improvement. This mandate has been designated to the Energy Endeavour Foundation (EEF), which is supported by the SDE Council of Experts, and endorsed by the US DOE to steward the Solar Decathlon in Europe, thus guaranteeing the continuity of the SDE.

It is also important that the EEF maintains an overall strategy of continuity in Europe, orchestrating the Calls for Cities and the Calls for Teams; stewarding the evolution of the SDE Rules; defining, and encouraging host cities to deploy, the general SDE communication strategy; overseeing and aligning SDE branding; providing editorial content and management of websites; coordinating social media activity; and coordinating with the other Solar Decathlon chapters worldwide.

On balance, the first three editions of the SDE met the objectives for the Competition in Europe, with notable innovations in the Competition and a significant social and media impact, especially taking into account the budget cuts suffered due to the economic crises of the time. This also resulted in a lack of institutional leadership, which led to the establishment of the EEF. The Energy Endeavour Foundation is a viable formula based on an entrepreneurial model rejuvenating and rethinking the Competition in Europe. The most recent edition in Szentendre (SDE19) is a success in itself. However, due to SDE19 organisers' misunderstanding of the SDE as a comprehensive event, its impact was severely limited. When host cities commit and deploy the recommended borderless communication strategies, the SDE editions can have extraordinary social and media impact.

The current edition (SDE21) rekindles the spirit and approach of the initial European Competition. The active collaboration between the EEF and the organisers team in Wuppertal promises to incorporate the accumulated experience of previous editions. With a focus in this edition on energy retrofitting in existing cities (a real European challenge), the SDE21 will take place in an accessible location in the city centre, with a strategy of activities and communication that should attract the broader public and targeted groups. Indeed, the organising team of the University of Wuppertal is incorporating into its strategy many of the lessons learned from this study.

Of note, however, is the missing support from the European Union and minimal sponsorship at a European level. This might mean that broad European impact could once again be limited. It begs the question: "How can we cooperate to make the Solar Decathlon Europe Competition a truly useful event to further European objectives and policies?"

solar
decathlon
europe

Framework to improve European outreach

The impact achieved by European universities participating in the Competitions can be improved both from an educational point of view and from a research and innovation point of view. In this sense, we need the leadership of an institution that takes advantage of the synergies that can be generated by the Competition. Through the support of the European Union (with programs such as ERASMUS +, COST Actions, EIP Climate KIK, etc.) this can bind networks of European universities, collaborating through mutually beneficial actions that support the objectives of the European Union, while contributing to a better and more sustainable Europe. Experience shows us that the EEF is essential, as it bridges the individual editions to ensure continuity and development. As a reference, work began on the design of the 10Action project in 2008, the kick-off meeting was held during the SDE10 Competition, and the greatest impact was achieved in the SDE12 event. This required leadership beyond the two-year cycle of the event, the kind of leadership that ensures continued commitment from participating universities, further promotion and development of European networks who articulate the important benefits of the Solar Decathlon Europe. These can be exchange programmes for students and professors, the generation of shared research projects that improve the technical innovation of solar houses and villas (smart grids, district heating & cooling, etc.), as well as other possibilities such as the maintenance of the Building Competition Knowledge Platform, and the relationship with SDE Alumni.

This initiative to promote communication and opportunities through a very ambitious strategy should be led by the EEF, which has revitalised enthusiasm for the SDE in Europe. Today, the EEF is the best bet to lead the process of deeper integration within the entire SDE community and broader outreach toward the European and worldwide communities. The EEF should serve as a lighthouse through these initiatives, promoting and coordinating the actions of the most active universities, participating as a partner to maintain the overall strategic momentum, energising the mobilisation of further SDE universities and institutions.

This expanded role for the EEF will require and benefit from the support of European entities such as the European Commission. Funding projects like 10ACTION allow the multiplication of an initial investment to develop activities that go beyond universities to reach children and young people (the future of Europe), citizens, and professionals. Other EU programmes can use the Solar Decathlon Europe events to leverage the creativity and enthusiasm of university students, our ambassadors in clean-energy sectors. The EEF is a stable, viable, agency for the SDE. However, without additional economic support, it will be difficult to expand the impact beyond its current scope. As a benchmark, the 10Action project budget was 2 200 000 €. With funding in this scale, it is possible to leverage the investment by complementing it with additional sponsors and the commitment of the past, current, and future participating universities. The EEF and the SDE events are undoubtedly a potential vehicle to maximise the impact of European Commission programmes toward the goals and ambitions of European Commission policies, especially in light of the current 'European Green Deal'.

# solar decathlon europe

## glossary

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# acronyms & abbreviations

| | |
|---|---|
| APDI | Association of Lighting Professionals |
| BACS | Building Automation and Control Systems |
| BEMS | Building Energy Management Systems |
| BIM | Building Information Modelling |
| BIPV | Building-integrated Photovoltaics |
| BUW | Bergische Universität Wuppertal, University Wuppertal |
| CAD | Computer Assited Drawing |
| CECODAS | European social housing agency |
| CERMI | Comité Español de Representantes de Personas con Discapacidad |
| CFA | Conditioned Floor Area |
| CIGS | Second generation of thin-film modules |
| CISOL | Centre d’Investigació Solar |
| COP | Coefficient of Performance |
| CPVT | Concentrating Photovoltaic thermal solar collectors |
| CSTB | Scientific & Technical Centre for Building |
| DHW | Domestic Hot Water |
| DIs | Sound Insulation Level |
| DOE | US Department of Energy |
| ECSO | European Construction Sector Observatory |
| EMI | Építésügyi Minőségellenőrző Innovációs Kht. |
| EPBD | Energy Performance of Buildings Directive |
| GAIA | Les Grands Ateliers Innovation Architecture |
| GBCE | Green Building Council Spain, the European social housing agency |
| GESLAB | Global Energy and Sustainable Laboratory in Building |
| HVAC | Heating, Ventilation & Air Conditioning |
| ICT | Information and Communication Technology |
| IDAE | Instituto de Diversificacion y Ahoro de Energía |
| IEA | International Energy Agency |
| MFH | Multi Family Home |
| MOU | Memorandum of Understanding |
| MV/LV | Medium Voltage / Low Voltage |
| NEED | National Energy Education Development Project |
| ONCE | Organización Nacional de Ciegos Españoles |
| PCM | Phase Change Materials |
| PMMA | Polymethylmethacrylate |
| PVT | Photovoltaic Thermal Hybrid Solar Collectors |
| RES | Renewable Energy Sources |
| SCC EIP | Smart Cities and Communities European Innovation Partnership |
| SD | Solar Decathlon |
| SDE | Solar Decathlon Europe |
| SDG | Sustainable Development Goals |

solar
decathlon
europe

| | |
|---|---|
| SFH | Single Family Home |
| SMEs | Small & Medium Enterprise |
| TES | Thermal Energy Storage |
| TGI beam | Truss Joist I-beam |
| UPM | Technical University of Madrid |
| U-Value | Thermal Transmittance |
| VET | Vocational and Educational Training |
| ZEB | Zero Energy Buildings |
| ZEC | Zero energy clusters |

solar
decathlon
europe

# definitions

| | |
|---|---|
| 10ACTION | European project that raises awareness about the need to use renewable energies and make responsible use of energy, and to promote energy efficiency and sustainability by disseminating knowledge gained during the Solar Decathlon Europe competition. |
| Action Clusters | Assemblies of partners committing to work on specific issues related to smart cities, by sharing the knowledge and expertise with their peers, giving added-value to their national and local experience and identifying gaps that need to be fulfilled at European level. |
| Assembly | Period of time between the arrival of trucks and the beginning of the contests on the SDE Solar Village. |
| Building Envelope | Physical barrier between the exterior and interior environments enclosing a dwelling. |
| Buffer Zone | Additional structural measures for the passive maintenance of indoor comfort. |
| Building Competition Knowledge Platform | Digital knowledge platform that secures the information, experiences and data from building energy competitions such as the Solar Decathlon and living labs worldwide. |
| Competition | All aspects of the Solar Decathlon Europe related to the 10 contests and the scoring of those contests, along with the project development of the Competition Houses. |
| Contest | The Solar Decathlon Europe Competition consists of 10 separately scored contests, each containing one or more sub-contests. |
| Contest Period | Period of days on SDE Solar Village when some or all contests are active. |
| Deliverables | The documents, drawings and other materials that SDE Teams must submit to the SDE Organisation that allow to study the projects, to familiarize with, and to explore the specific technical details of each of them. |
| Disassembly | Period of time between the conclusion of public tours and the completion of the SDE Solar Village clean-up. |
| Energy Endeavour Foundation | The Energy Endeavour Foundation is the legal platform that desginates and stewards SDE host cities in the organisation and promotion of the SDE competition event. |
| Energy Grid | Bi-directional, AC electrical network system installed on the Competition site which will constantly and individually measure the contribution and consumption of electrical energy of each House. |
| Event | Activities that take place on SDE Solar Village including, but are not limited to, registration, assembly, inspections, contests, special events, public exhibits, and disassembly. |

solar decathlon europe

| | |
|---|---|
| **Floor Plan** | Drawing that illustrates the layout of a dwelling from above. |
| **House** | Complete assembly of physical components installed on the SDE Solar Village, in compliance with the SDE Rules. |
| **Living Lab** | A user-centered, open-innovation ecosystem, operating in real-life environments. It integrates concurrent research and innovation processes within public-private partnerships to work on new solutions. |
| **$N_{50}$** | Air leakage rate given as air change per hour at 50 Pascal pressure difference. |
| **Net Plus Energy Buildings** | Dwellings that are typically characterized by low energy consumption through passive energy design strategies. |
| **Net Zero Energy Buildings** | Dwellings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. |
| **Passive Design Strategies** | Any form of strategy that use ambient energy sources instead of purchased energy like electricity or natural gas. |
| **Passive Evaluation Period** | Period of time during the SDE Competition where the participating houses are allowed to use only passive cooling or heating. |
| **Phase Change Materials** | Substances which absorb or release large amounts of latent heat when they go through a change in their physical state, i.e. from solid to liquid and vice versa. |
| **Photovoltaic System** | Renewable energy technology that transforms the energy from the sun into electricity using photovoltaics. These photovoltaics, better known as solar panels, provide a reliable green energy solution. |
| **Prefabrication** | The process of assembling components of a structure in a factory or other manufacturing site, and transporting complete assemblies or modules to the construction site where the structure is to be located. |
| **Project** | All activities related to the Solar Decathlon Europe in from the initial meetings through to the conclusion of the event. |
| **Public Showcase** | Areas of the SDE Solar Village open to the public during designated hours. |
| **Rules** | Principles or regulations governing conduct, action, procedure, arrangement, etc., for the duration of the SDE Project. |
| **SDE Jury** | Group of individuals selected by the SDE21 Organisation to make evaluations on a specific aspect of each Team's project according to SDE21 contests. |

solar
decathlon
europe

| | |
|---|---|
| **SDE Organisation** | The SDE Organisation is a joint SDE/EEF consortium consisting of a supervisory board, the SDE Organisers and the divisions according to the organisational chart. |
| **SDE Organisers** | The designated SDE officials responsible for the implementation and execution of the divisions described in the SDE organisational chart. |
| **SDE Solar Village** | Competition Site, where the Teams' Houses are assembled along with the common areas needed for the Competition development. |
| **SDE Building Code** | A set of design and construction standards set forth and enforced by the Solar Decathlon Europe Building Official for the protection of public health and safety during the event. |
| **SDE Council of Experts** | The SDE Council of Experts is a contributing group of SDE legacy experts supporting the EEF's Solar Decathlon Europe mandate, committed to the longterm impact & vitality of the SDE. Members provides initial, voluntary input to the EEF, bringing experienced counsel for SDE-related topics. |
| **Smart Cities Community** | Entities using technological solutions to improve the management and efficiency of the urban environment. |
| **Solar Decathlon Europe** | A university-level student competition in Europe for sustainable, energy-efficient architecture and engineering. Focusing on 10 Contests, Teams compete in the design, construction and management of individual, solar-powered, and resourceefficient homes. |
| **Solar Envelope** | Spatial dimensions defined by the SDE Organisers in which each House and all items associated with the House must stay within to protect a neighbour's right to the sun. |
| **Solar Gain** | The increase in thermal energy of a space, object or structure as it absorbs incident solar radiation. |
| **Sub-Contest** | An individually scored element within a contest. |
| **Sub Contest - Juried** | Sub Contest based on jurors' assessment. |
| **Sub Contest - Measured** | Sub Contest based on task completion or measured performance. |
| **Surface Cladding** | Components that are attached to the primary structure of a dwelling to form nonstructural, external surfaces. |
| **Thermal Energy Storage** | An environmentally friendly technology that allow us to temporarily store energy produced in the form of heat or cold for use at a different time. |

solar decathlon europe

Stand: July 2020

# solar decathlon team abbreviation list

(Chapter & edition: SDUS02)

## US 2002

| BCKP_Code | Team Name |
|---|---|
| AUB | Auburn |
| CMU | Carnegie Mellon |
| CRB | Colorado |
| DLW | Delaware |
| MRY | Maryland |
| MSR | Rolla |
| NCL | UNC Charlotte |
| PRC | Puerto Rico |
| SHR | Crowder |
| TAM | Texas A&M |
| TEX | Texas |
| TSK | Tuskegee |
| VGT | Virgina Tech |
| VIR | Virginia |

(Chapter & edition: SDUS05)

## US 2005

| BCKP_Code | Team Name |
|---|---|
| CAL | CalPoly |
| CMU | Pittsburgh Synergy |
| COR | Cornell |
| CRB | Colorado |
| FIU | Florida International |
| MCH | Michigan |
| MON | Canada |
| MRY | Maryland |
| MSD | UMassDartmouth |
| MSR | Rolla |
| NYT | NYIT |
| PRC | Puerto Rico |
| PTN | Madrid |
| RID | RISD |
| SHR | Crowder |
| TEX | Texas |
| VGT | Virgina Tech |
| WSH | Washington |

(Chapter & edition: SDUS07)

## US 2007

| BCKP_Code | Team Name |
|---|---|
| CIN | Cincinnati |
| CMU | Carnegie Mellon |
| COR | Cornell |
| CRB | Colorado |
| DRM | Darmstadt |
| EAS | MIT |
| GEO | Georgia |
| IUC | Illinois |
| KNS | Kansas |
| LWC | Lawrence |
| MON | Montréal |
| MRY | Maryland |
| MSR | Rolla |
| NYT | NYIT |
| PRC | Puerto Rico |
| PST | Penn State |
| PTN | Madrid |
| SAN | Santa Clara |
| TAM | Texas A&M |
| TEX | Texas |

(Chapter & edition: SDUS09)

## US 2009

| BCKP_Code | Team Name |
|---|---|
| ABT | Team Alberta |
| ARZ | Team Arizona |
| BAC | Team Boston |
| COR | Cornell Team |
| DRM | Team Germany |
| IOW | Iowa State University |
| IUC | Team Illinois |
| KTY | Team Kentucky |
| LFY | BeauSoleil |
| MIN | Team Minnesota |
| MIS | Team Missouri |
| OSU | Team Ohio State |
| PRC | Team Puerto Rico |
| PST | Pennsylvania State University |
| PTN | Team Spain |
| RCU | Rice University |
| SAN | Team California |
| VGT | Virginia Tech |
| WRF | Team Ontario |
| WSM | Team Wisconsin-Milwaukee |

solar decathlon europe

(Chapter & edition: SDUS11)

## US 2011

| BCKP_Code | Team Name |
|---|---|
| ABT | Team Canada |
| APP | Appalachian State University |
| CHI | Team China |
| EAS | Team Massachusetts |
| FIU | perFORM[D]ance Team |
| FLA | Team Florida |
| GHT | Team Belgium |
| IUC | Team Illinois |
| MLB | Team Middlebury |
| MRY | WaterShed |
| NJY | Team New Jersey |
| OSU | The Ohio State University |
| PAR | Team Parsons NS Stevens |
| PUR | Team Purdue |
| TEN | Team Tennessee |
| TWV | Tidewater Virginia |
| UNY | Team New York |
| UNZ | FIRSTLIGHT NZ |
| USC | Team SCI-ARC / CalTech |

(Chapter & edition: SDUS13)

## US 2013

| BCKP_Code | Team Name |
|---|---|
| ABT | Team Alberta |
| ASU | aSUNm |
| AUS | VUT Team Austria |
| CDC | Team Capitol DC |
| CZR | Team Czech Republic |
| MIS | Missouri S&T |
| MLB | InSite |
| NCL | Team UNCC |
| NRW | Delta T-90 team |
| OTQ | Team Ontario |
| PHX | teamkentuckian |
| SAN | Santa Clara |
| STC | Team USC |
| STF | Stanford University |
| STV | Stevens Institute |
| TXS | Team Texas |
| ULV | Team Las Vegas |
| USC | SCI-Arc/Caltech |
| WVG | Team West Virginia |

(Chapter & edition: SDUS15)

## US 2015

| BCKP_Code | Team Name |
|---|---|
| AGS | Aggie SOL |
| ALF | Team NY Alfred |
| CAP | CalPoly |
| CDS | Team Orange County |
| DUR | DURAHOME |
| EAS | Massca |
| GRW | NY BUFF |
| INP | Team Clemson |
| MIS | Missouri S&T Solar House Team |
| NEX | Team Texas/Germany |
| RFH | Sacramento Solar Nest |
| SAC | Solarnest |
| SHR | Crowder/Drury |
| STV | SURE HOUSE |
| WVG | WVU-UTV |
| YHO | Yale |

(Chapter & edition: SDUS17)

## US 2017

| BCKP_Code | Team Name |
|---|---|
| AGS | UC Davis |
| ALC | Team Alabama |
| BKY | UC Berkeley/U of Denver |
| DAY | Team Daytona Beach |
| MIS | Missouri S&T |
| MRY | Maryland |
| NTW | Northwestern |
| SWS | Swiss Team |
| ULV | Team Vegas |
| UTR | Netherlands |
| WLO | Wash U |

solar decathlon europe

(Chapter & edition: SDE10) **Europe 2010**

| BCKP_Code | Team Name |
|---|---|
| AMP | Napevomo |
| BER | Living Equia |
| BUW | Team Wuppertal |
| CEU | SMLhouse |
| GRE | Armadillo Box |
| HFT | Home+ |
| HUT | Luuku House |
| IAA | FabLab House |
| ROS | Team IKAROS Bavaria |
| TUC | Sunflower |
| TUS | Bamboo House |
| UDS | Solarkit |
| UDV | Urcomante |
| UOF | RE:FOCUS |
| UON | Nottingham HOUSE |
| UPC | LOW3 |
| VGT | LumenHAUS |

(Chapter & edition: SDE12) **Europe 2012**

| BCKP_Code | Team Name |
|---|---|
| ABC | Team ABC |
| AND | Andalucia Team |
| BME | Odoo Project |
| BRA | Team Brasil |
| BUC | Prispa |
| CEU | CEU Team Valencia |
| CUJ | Chiba University |
| DTU | Team DTU |
| EHU | EHU Team |
| FAU | Cem+nem- |
| HTW | Ecolar |
| ROM | Med in Italy |
| RWT | CounterEntropy |
| STS | estonyshine |
| TJU | Tongji Team |
| TRA | Canopea |
| UDZ | Grupo pi Unizar |
| UPC | (E)CO Team |

(Chapter & edition: SDE14) **Europe 2014**

| BCKP_Code | Team Name |
|---|---|
| ATL | Atlantic Challenge |
| BAR | Team Resso |
| BUC | Team EFdeN |
| CUJ | Chiba University |
| DEL | Prêt-à-Loger |
| DTU | Team-DTU |
| FNX | Team Fenix |
| INS | Team Inside Out |
| KMU | KMUTT-Team |
| LUC | Team Lucerne |
| MEX | Team Mexico Unam |
| OTP | Team On Top |
| PAR | Team Paris |
| PLT | Plateau Team Universidad de Alealá |
| REC | Team Reciprocite |
| ROF | Team Roof Top |
| ROM | DenCity |
| SHU | Team Shunya |
| TEC | TEC Team San José |
| UNI | Team Unicode |

(Chapter & edition: SDE19) **Europe 2019**

| BCKP_Code | Team Name |
|---|---|
| BUD | Team BME |
| DEF | Team MOR |
| GUB | Team Mobble |
| KMU | Team NEST |
| MIH | Team Someshine |
| PLF | Team Habiter2030 |
| SEV | Team Aura |
| TUB | Team Over4 |
| UPC | Team TO |
| VAL | Team Azalea |

solar
decathlon
europe

(Chapter & edition: SDE21) **Europe 2019**

| BCKP_Code | Team Name |
|---|---|
| BKU | Team SAB adaptive living quarter |
| CHA | Team C-Hive |
| CTU | Team FIRSTlife |
| FHA | Team LOCAL+ |
| GRE | Team Aura |
| HBC | Team X4S |
| HFT | Team col.lab |
| HSD | Team HSD - MI-MO |
| ION | Team EFdeN |
| KIT | Team RoofKIT |
| KMU | Team UR-BAAN |
| NCT | Team House for All |
| ROS | Team Level Up |
| TUD | Team SUM |
| TUE | Team VIRTUe |
| UPH | Team Lungs of the City |
| UPV | Team Azalea |

(Chapter & edition: SDC13) **China 2013**

| BCKP_Code | Team Name |
|---|---|
| ALF | Team Alfred and Guilin |
| ASH | Team Iran-SUES |
| AUC | Team AUC |
| BJN | Team BJTU |
| CAS | Team Heliomet |
| CHL | Team Sweden |
| ISR | Team Israel |
| MES | Team Turkey |
| MLY | Team Solar-Home-UTM |
| MNG | Team Green Sun |
| NJH | Team NJIT-Harbin |
| PKI | Team PKU-UIUC |
| SCT | Team SCUT |
| SEU | Team SEU |
| SGP | Team NUS |
| SGU | Team SJU |
| SJT | Team SJTU |
| THF | Team THU-FIU |
| UOW | Team UOW |
| WGN | Team BE-MA-NY |
| XMU | Team Xiamen Univ |
| XUT | Team XAUAT |
| BJU | Team BJTU-Jolywood |

(Chapter & edition: SDC18) **China 2018**

| BCKP_Code | Team Name |
|---|---|
| COM | Team COMAS-Afeka |
| HUN | Team Solar Offspring |
| IIB | Team Shunya |
| IIY | Team Turkey |
| MCG | Team Montreal |
| NIF | Team CNBM-WIN |
| NNC | Nottingham-Ningbo |
| PKU | Team PKU (exhibition) |
| SCT | Team SCUT-POLITO |
| SES | Team SUES-XD |
| SIE | Team SIE-LNKT |
| SJI | Team SJTUIUC |
| SSA | Team Korea |
| SUB | Team TUBSEU |
| SXR | Team JIA+ |
| TRS | Team Canada |
| TUD | Team TJU-TUDA |
| TUN | Team THU |
| UHK | Team B&R |
| WUS | Team WashU (exhibition) |
| XAT | Team XAUAT |
| XJW | Team XJTU-WNEUPOLIMI |
| YII | Team YI |

(Chapter & edition: SDLAC15) **Latin America & Caribbean 2015**

| BCKP_Code | Team Name |
|---|---|
| BLV | YARUMO |
| BVO | MIHOUSE |
| COL | UNSOLAR |
| CTL | CASA SOLDiARIA |
| CWS | HISCALI |
| ESM | Kuxtal |
| IPR | Proyeto Ayni |
| JCU | Casa ALERO |
| JVB | PEI |
| LAD | más Huerto+casa |
| LON | Heliot Met |
| PNE | PANAMASS |
| SOL | HABITEC |
| SVC | VRISSA |
| ULV | Wiwa Team |
| URG | LA CASA URUGUAYA |

solar decathlon europe

*(Chapter & edition: SDLAC19)* **Latin America & Caribbean 2019**

| BCKP_Code | Team Name |
|---|---|
| AET | AEter |
| AUR | AURA |
| BOH | BOHIOS |
| CAH | Chamaleon House |
| CNO | Casa NORDESTE |
| INN | InnoNativo |
| JAT | Játi |
| MIN | MINGA |
| PMV | PEI MÁQUINA VERDE – EL ARCA |
| PUA | PuertAbierta |
| PVV | PV4 |
| TON | TONAL |
| TUH | TUHOUSE |
| VRI | VRISSA |
| WKP | WILLKALLPA |

*(Chapter & edition: SDME18)* **Middle East 2018**

| BCKP_Code | Team Name |
|---|---|
| ABU | Team NYUAD |
| AJU | Team AQUA GREEN |
| BTK | Team BaityKool |
| CTG | Team TDIS |
| EFN | Team EFdeN |
| EHV | Team VIRTUe |
| ITA | Team Sapienza |
| KSD | Team KSU |
| MLY | Team MizanHome |
| ORA | Team ORA |
| RAK | Team AURAK |
| SHU | Team Know-Howse |
| UAE | Team Jeel |
| UOW | Team UOW |
| VGT | Team Virgina Tech |

*(Chapter & edition: SDA19)* **Africa 2019**

| BCKP_Code | Team Name |
|---|---|
| AFH | A' Free Home |
| AFT | Afrikataterre |
| AGR | Africa Golden Ryad |
| BAA | Bayti_Akhdar |
| BOS | BOSPHOROUS |
| CJE | NEOPETRA |
| DAR | DarnaSol |
| ECD | E-CO-Dar |
| INH | InterHouse |
| JUJ | Jua Jamii |
| MAH | Mahali |
| MRM | Modularity |
| OCU | OCULUS |
| PLL | PLUG & LIVE |
| SOL | SOLARTIGMI |
| SUP | SUNIMPLANT |
| SUT | Solar-ution |
| TAD | TADD-ART |
| TDA | TDART |
| THR | THRIVE |

# solar decathlon europe

## colophon

Funded by:

European Commission

THE EC TENDER ENER / C2 / 2016-502 "SOLAR DECATHLON EUROPE: AN ANALYSIS OF THE RESULTS" WAS JOINTLY CONDUCTED BY PNO CONSULTANTS, UNIVERSIDAD POLITECNICA DE MADRID, BERGISCHE UNIVERSITÄT WUPPERTAL, TECHNICAL UNIVERSITY OF DELFT AND THE ENERGY ENDEAVOUR FOUNDATION.

solar
decathlon
europe

# project partners

**PNO** PNO Consultants
Laan van Zuid Hoorn 15, 2280 CA Rijkswijk, Netherlands
http://www.pnoconsultants.com
info@pnoconsultants.org
Anne-Ingeborg Van luijn Anne-Ingeborg.VanLuijn@pnoconsultants.com
Marco Bakker
Roel van der Veen

**EEF** Energy Endeavour Foundation
Godelindeweg 62, 1412 HE Naarden, Netherlands
http://www.energyendeavour.org
info@energyendeavour.org
Louise Holloway louise.holloway@energyendeavour.org
Geraldine Lorijn geraldine.lorijn@energyendeavour.org
Claudio Montero claudio.montero@energyendeavour.org

**UPM** Universidad Politecnica de Madrid

http://www.upm.es

Sergio Vega
Beatriz Arranz
Richard Amaral

**BUW** Bergische Universität Wuppertal

http://www.uni-wuppertal.de

Karsten Voss
Susanne Hendel

**TUD** Technische Universitaat Delft
Julianalaan 134, 2628 BM Delft, Netherlands
http://www.tudelft.nl
info@tudelft.nl
Peter Russell p.j.russell@tudelft.nl