The SOLAR DECATHLON Knowledge Platform – Concept and Initial Application

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Abstract

The student competition Solar Decathlon (SD) is an established platform to demonstrate and analyze approaches to energy efficiency and solar energy utilization in residential buildings. Its outstandingly unique feature of generating at least 15 to 20 highly comparable houses each competition opens the possibility of being a source for research projects with a lack of case studies. Due to the main goal of previous SD competitions of being a communicative event to educate the general public, how to use renewable energy, the results from previous competitions do not meet scientific demands. Knowledge of the previous results is crucial to influence future SD results to be useful outside the competition for research purposes. This paper evaluates the possibility of using the SD houses as building performance test facilities and shows the need and application of a SD database with harmonized documentation of previous SD houses as well as the possibilities to use the data.

Keywords: Solar Decathlon, Student Competition, Knowledge Platform, Case Studies, IEA, Technology Trends

1. Introduction

The majority of research projects analyzing building performances lack of a sufficient number of case studies. In particular, projects researching the whole building performance instead of components face significant challenges in finding enough comparable test facilities. The following examples illustrate the difficulties of building performance case study projects. Either a suitable test facility could not be found at all and had to be built specifically for the project, like the Twin houses (link 1) at the Fraunhofer IBP Campus in Holzkirchen Germany, or the analysis had to cover a very long period in order to include a sufficient number of projects were analyzed but over a large timespan, like in the Zaragoza case study (Monzón, López-Mesa, 2017), which lasted from 1945 to 1975. Only few projects have the time and/or the money to follow such elaborate approaches. Accordingly, also the IEA EBC Annex 58 (Strachan, 2016) described the lack of financial means and time as main reason for the absence of suitable test facilities in building performance case study projects. Another example illustrating the missing comparability of houses in such studies and how the outcome would look like without investing extra time or money is the German initiative for accompanying research of buildings (Voss, 2016). Although the last project phase lasted 10 years and a total of 44 houses could be evaluated, only performance evaluations of components were possible. And even with a focus on components hardly five to ten buildings could be compared to underline the findings. That also reflects in the chapters of the final book publication “EnOB Gebäudeperformance”. Addressing the whole building performance within the EnOB context would lead to no comparable houses for such a study. Finally, the ongoing search for comparable test facilities in the building sector within current projects like the Annex 68 and 71. (link 2, link 3) shows the urgent need for the availability of more test objects right now.

For this problem, the Solar Decathlon (SD) with its large number of comparable houses could be the solution.

The SD, with its unique competition concept, challenges international student teams to design, build and operate a sustainable and highly efficient single-family home. Since the first competition in 2002, 15 SDs have been held worldwide. The current boost of interest accelerated by national and international approaches to slow down climate change by improving energy policies has led to seven new SD events being held through the end of 2021 (figure1). With 260 highly comparable SD houses already built, documented and intensely monitored and another approximately 100 new houses on the horizon, now is the right time to think about how the SD could be used as a source for case studies in the future.

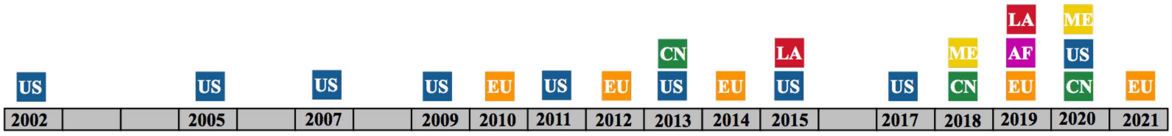

Fig. 1: Global SD Events timeline. US: United States of America; EU: Europe; CH: China; LA: Latin America and Caribbean; ME: Middle East; AF: Africa
Source: S. Hendel, Wuppertal University

Some houses were already used as test facilities or were further analyzed besides the competition documentation and monitoring. However, this was limited to studies and projects by the teams who built the respective house or scientist who at least had a direct link to one of the houses. For example, the Energy and Buildings special edition on the findings and research based on the SD 2012 includes numerous studies showing what can be done with SD results (Vega, 2014). From 23 papers published in that edition 18 papers are focused on one specific house and were written by at least one team member who was directly connected to that house. Two of the other five papers in that issue describe the concept of the SD competition or one of the ten contests. The remaining three papers are analyzing all SD houses in that SD EU 2012 competition with a focus on a specific topic, like Building integrated PV (Cronemberge, 2014) and passive technologies (Rodriguez-Ubinas, 2014). These three papers about all SD EU 2012 were only possible because the SD organizers were directly involved in those studies and had a more complete access to the houses data. This shows that case study projects with SD houses are already possible, but generally limited to approaches where no other data is needed than what can be generated by the team's own house. The fact that there is such little research besides the projects of the teams around their own house indicates a problem with the general availability of SD data. This can be confirmed when looking at the existing data. In the past, the enormous amounts of data have been recorded in very different and often confusing way resulting in a significant lack of quality and structure. In addition, the data sets are usually incomplete, lacking for example in general building descriptions, including size, material or technologies used, performance data of the technical building components and descriptions of the monitoring set-up.

Therefore, the first step in order to make the SD feasible as a source for case studies needs to be the preparation of the existing SD data. Based on the knowledge generated by analyzing the existing data, in a second step the documentation of the future SD houses needs to be optimized for research purposes.

This idea was already picked up by the Annex 74 "Competition and Living Lab Platform" (link 4) to ensure the generation of knowledge of the past SD competitions to profoundly influence future SD´s to be able to use the houses and data for projects like the above mentioned (Voss, 2016).

For this specific purpose, the Building Competition Knowledge Platform (KP) has been created and will be further developed in close connection with the organization of future SDs. The KP is a high efficient tool to achieve a more scientific output from the SD by making the existing data available and usable for research purposes and can also be employed to optimize the way in which the data will be documented in the future. (link 5)

In the following three chapters, the scientific usability of SD data by implementing the KP will be shown. First, the general features for making the existing data usable and available by applying the KP will be described. Secondly, a further description of the technology tags will be presented which constitute the most important feature of the KP allowing the users to deal with wide spread information like the many different technologies used in the SD houses. Ultimately, by using the KP to analyze the existing SD data, the specific suitability of the SD houses as test cases for projects outside the competition framework will be proven.

2. The Knowledge Platform

The KP is a tool to store and make the existing comprehensive SD data available to potential users. Also with the KP an optimized way of documenting the SD data will be presented. Input and feedback for the setup of the KP was gathered within the Annex 74 (link 4) framework.

The KP is already running and will already be used by the teams participating in the SD Middle East 2018. The combined screenshots in figure 2 illustrate its current set-up. Here it can be seen that the data stored in the KP is organized by editions and competitions. An implemented google map helps to find a house by location. A scoring overview that is linked to the team fact sheets allows users to find a house by competition success.

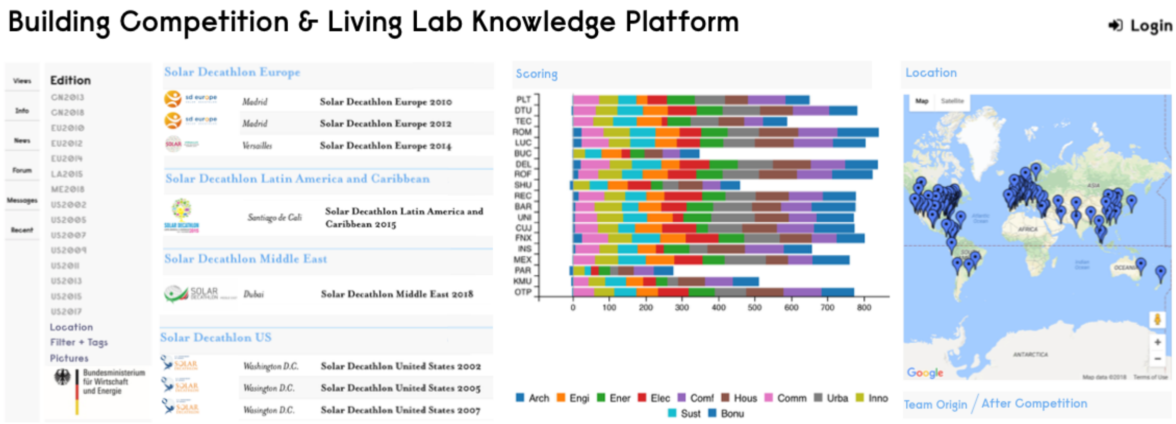

Fig. 2: Illustration of the Building Competition and Living Lab Knowledge Platform.
www.building-competition.org
Source: S. Hendel, University of Wuppertal

With every SD competition comes a flood of data. A complete set of existing data would contain competition rules, team project manuals, team project drawings, team jury narratives, jury reports and monitoring description and monitoring data. As far as available, documents from all the past SD competitions are already stored in the KP. However, not once a full set of data could be achieved, mainly because the data was generated but not stored or shared. For example, only the final and one out of 7 or 8 team deliverables could be located. Usually, the final deliverable set contains the “as build” description of the house with detailed of the concept, design and all components. For the SD US and the SD EU at least a full set of team documentation could be located and stored in the KP.

It is to be assumed that the existing team documents contain all the necessary information, but they are usually as voluminous as 1,000 pages per team. Because of the size and the various structure of these team documents, the information they deliver is not easy to access.

The KP not only stores the data in a unified and filtered way to make the existing data usable, it also is online accessible. Team fact sheets were created and filled with general information. The fact sheets are based on information given by the existing team project manuals and are also exportable as an Excel file. Besides house size, envelope quality, team heritage location, scoring, general descriptions of the HVAC system, PV system and an estimated energy balance are also included in the fact sheets. Tags are available to be added to every house documentation and can be used as a filter system for analyses. Tags are set up to identify the technologies or materials used in the houses. The topics addressed by the tags are constantly under development and will be further amended based on the needs of future SDs. Because the tags are a crucial feature of the KP to make the SD output usable for case study research they will be described in detail in chapter “3: Technology tags.”

To secure comparability, factsheets and tags are based on global templates. All existing information stored in the fact sheets and tags was researched manually within the German SD research project (cf. Acknowledgement). Fact sheets and tags can be used as a two-layer analysis tool. The tags are for filtering the data and to give an overview of technologies used. The fact sheets provide additional and more descriptive information.

Besides the incomplete data sets available, there is another problem: Even the complete existing documentation as it was recorded and structured within the KP until today would lack information and quality crucial for the use of the data outside the competition. Generally, detailed information about power and performance of applied technologies are not or not completely available. Also, information about control strategies are not included in the majority of the existing documentation, but would be needed for building performance analysis. Monitoring Data of the houses, including indoor temperature, humidity, air quality, energy generation, energy consumption by appliances, light and HVAC are available. But a detailed description of the monitoring set up including descriptions of the sensors, measuring interval and a documentation of the measurement process are missing. Therefore, the monitoring data is useless outside the competition. These here descried missing information can be documented for future SDs. For example, for the SD EU 2014 a template to describe the input for an indoor comfort and energy balance simulation tool was located. That templated is called the “Simulation Input Report” (link 6). The teams in the SD 2014 had to deliver very detailed descriptions about their houses, technical components, materials, control strategies and even usage scenarios. This templates only asked for information that would be needed to feed in a simulation tool., but there was no template to deliver the simulation post-processing data. Also, the SIR was not part of the final team deliverable. This is reflected on the delivered data from the SD EU 2014 teams. The respective house descriptions contain data partially asked for in the SIR but without any useable context or structure. However, it demonstrated that it could be feasible to ask for specific detailed information and to include it in the structured documentation of future SD houses.

Fact sheets and tags are the base for future SD documentation to secure a full set of data that has the quality to be used for building performance case studies. Fact sheets of future SD houses will contain all information that were available of past SD houses and they will be optimized by possible information like presented by templates like the SIR. Another optimization for future documentation is that future teams and organizer will deliver their data directly to the KP. This will to reduce time for editing the documentation and will securing complete data sets. But by allowing teams and SD organizers using the KP and editing certain parts of it a user rights management needs to be in place to still make a fair competition possible. Presently five different user types with specific rights to see and edit the KP are defined and therefore the KP is fully operational. The first teams filling in their house description are the teams of the SD ME 2018, followed by the SD EU 2019, that is possible because the SD organizers are part of the Annex 74 and agreed to this support. Also, SD Organizers should store their data in the KP. Interesting organizer data would be for example background information of rules changes or developments. The log in bound user rights management also offers the possibility to make the information stored in the KP as easy as possible accessible without violating copy rights.

With the improved documentation as suggested here the SD could be a constantly growing source for building performance case study projects.

3. Technology Tags

3.1 Need for tags

Tags are a feature of the KP to make the SD data effectively usable for building performance case studies, because they allow a broad overview of house specifications. They are used to simply label a house with a large number of non-descriptive single information of any kind. The tags can be used as a filter for specific houses or to get an overview what can be found in the SD houses.

The tags in the KP are currently set for technologies and materials used, because this is the main difference between the houses and the most important part of the building to influence its performance. Besides the technological differences the SD houses are uniquely high comparable because of the competition framework. They have the same user type and a similar size and for each competition at least 15 to 20 houses are located and tested at the same time and the same location.

Tags can be used as a filter but also for trend analysis like, e.g., market studies as published by NREL (Simon, 2017). For that paper, the SD US houses between 2002 and 2015 were analyzed with regards to the questions which technologies were used, how frequent they were applied and whether the SD served as a platform to get certain technologies market ready. This kind of research based on the SD houses and without the KP was only possible because of comparable documentation as a result of the work by a continuous organization team for the SD US between 2002 and 2015. Now the KP also allows analyses of houses other than the SD US houses.

3.2 Conception of tags

The tag structure is based on how technologies or materials can be applied to secure indoor and user comfort under certain environmental influences. Therefore, the structure of KP tags is based on the connection between environmental conditions and comfort needs. Comfort conditions for temperature, air quality, humidity and light level always have to be in a certain range to fulfill the user needs. The range of the comfort expectations can vary based on the local climate and cultural influences. Therefore, for each location, a certain comfort range is defined and simplified in the rules for every SD competition. The significance of the environmental conditions at each event location is addressed in figure 3.

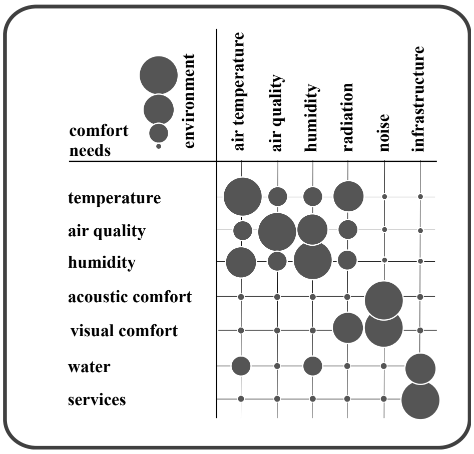

Fig. 3: Connection between the environmental conditions and the user comfort expectations. The size of the dots marks the importance of the relations. The bigger the dot, the stronger the influence of an environmental factor on a comfort need. Source: S. Hendel, Wuppertal University

The above-mentioned comfort expectations are complemented by water needs and service needs. The domestic hot water needs and the electricity for house appliances influence the total building energy performance.

The tags set in the KP help to understand the technologies used by the teams to fulfill the competition, comfort and general design expectations and are mainly based on the user needs as described in figure 3.

The tags are sub-structured based on how they work to ensure a comfortable state (figure 4). If a user need is fulfilled, it can be "protected" from environmental influences. If a comfortable state is not reached, it usually can be by "generation". For instance, heat, cold, service, humidity and energy can be "generated" to satisfy a user need. Everything generated needs to be "distributed" from the place of generation to the place where it is needed. If there was generated more than what was needed, then it can be "stored". The connection between needs, protection, generation, distribution and storage is described by "control".

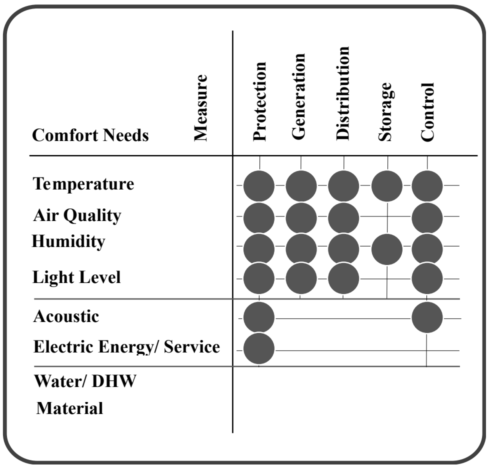

Fig 4: Measures to fulfill comfort needs as a structure base for the technology and material tag list. Source: Wuppertal University; Hendel

As shown in figure 4, some sub-categories need to be skipped, because there is, for example, no storage of light. Based on the experience in researching the SD Europe houses and designing and testing the already implemented fact sheets, it is very likely that the suggested tag structure will withstand all further research (figure 4). A full list of all preconfigured tags can be found at the KP (link 7).

At the moment, 160 tags are already preconfigured and set for the SD EU teams. A finding of tagging the SD EU houses is that the SD houses are particular suitable for building performance case studies, as shown in chapter 4.

4. Particular suitability of the SD houses as case studies

Many current building performance case studies focus on efforts to better understand buildings or components in order to improve them. In this context, improvement mostly means making a contribution to slow down climate change while maintaining at least the same high level of comfort. In addition to energy savings, the use of renewable energies is also of interest in residential construction. All of these projects either need or could profit from case studies. The general suitability of the SD houses for such projects was already established above. Furthermore, they are particular suitable for building performance case study projects, because they are only powered by solar energy and significantly smaller than common houses and that will be presented in this chapter. The following arguments could only be established by applying the two-stage analysis possibility of the KP. The first stage is using the tags to get an overview and filter for specific houses and secondly getting more information about the filtered houses from the fact sheets.

4.1. Smaller building sizes lead to better test settings

The SD houses are much smaller than common buildings and are therefor under a stronger environmental influence. However, that stronger influence makes the houses even more suitable for building performance studies, because they function like a lab test under practical conditions. Under extreme boundary conditions, insights about performance can be generated because they are less dependent on small and common disturbances. For example, if an active cooling system has a malfunction, but the need for cooling could be satisfied also by passive systems like shadowing and ventilation, the lack of performance of that active cooling device could be not detected. But if the cooling need is exceptionally high because of high solar irradiation and high environmental temperature, then this would increase the probability to find that malfunction.

By looking at the past SD EU houses, a smaller building size means a larger A/V value and also less conditioned floor area per inhabitant than in common homes. The size of the SD houses is a direct result of the competition rules. The maximum conditioned floor area in 2010 was limited to $74m^2$, in 2012 limited to $70m^2$ and in 2014 limited for a single-story building to $70m^2$ and a two-story building to $110m^2$. The conditioned floor area of the analyzed SD EU houses is illustrated in figure 5 showing that the majority was smaller than $60m^2$.

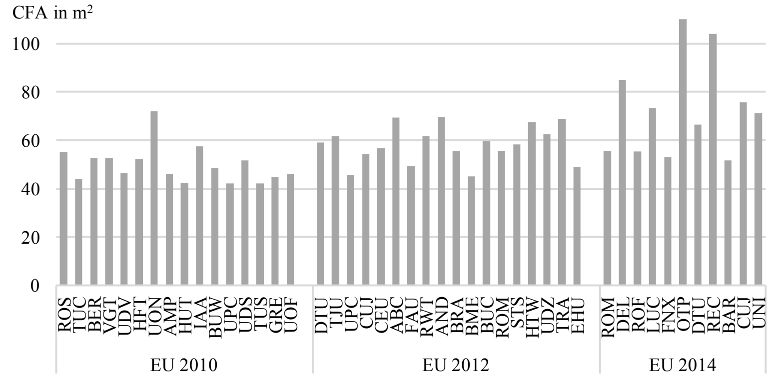

Fig. 5: The conditioned floor area (CFA) is a standard value that is stored in the fact sheets. Conditioned floor area is defined by the SD EU rules as: "Covers and constructed area remaining when walls, columns, stairs shaft, under 1.8m high space and closets or any storage or technical element build from floor to ceiling are excluded" (SD EU 2014). Only interior and conditioned spaces are part of this area. Here the CFA of the SD EU houses of 2010, 2012 and 2014 are illustrated.

Source: Wuppertal University; Hendel

A result of the small size and the fact that the SD houses are usually designed for a two-person household is that they offer less living area per inhabitant. The about $70m^2$ per house are corresponding to $35m^2$ per person. This is significantly less than the common $46.5m^2$ per person in Germany (Statistisches Bundesamt, 2017) and less than the European average of $42.6m^2$ per person (European Commission, 2011).

More importantly, because of the small sizes, the houses usually have a higher A/V ratio than normal single-family homes (SFH) like the two exemplary single-family homes evaluated in a net-zero energy building research project (Voss, Musall, 2012) (figure 6). Their envelope area is therefore significantly higher, which makes the SD houses more exposed to environmental factors like temperature and irradiation. However, the majority of the SD houses achieve comfortable indoor climate conditions with a highly efficient use of solar energy.

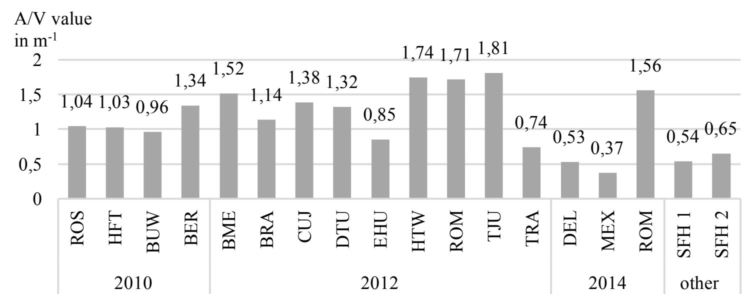

Fig. 6: Surface-to-volume ratio of the SD EU houses of 2010, 2012 and 2014, and, as a comparison, the A/V ratio of two single family homes are illustrated here. The comparison buildings were analyzed in a net zero energy building research project (Voss, Musall, 2012).

Source: Wuppertal University; Hendel

The most important reason why the houses could usually deal well with the stronger environmental influences by using solar energy is, that due to the larger A/V value they have more surface area per conditioned volume available to use for solar energy generation.

4.2. Extensive use of solar energy in SD

National and international approaches to slow down climate change, among other things, led to a current boost of interest in the SD. The extensive use of renewable energy and especially solar energy in residential buildings with the goal to minimize CO_2 emissions is demonstrated by the SD houses. Using their results can give valuable insights also for the building practice. As already explained above, the SD houses achieve a comfortable indoor climate by using only solar energy and that in a highly efficient manner by using a complex and innovative technology set-up. To see with which technologies the houses were equipped to perform best under these boundary conditions the technology tags could be applied. Here the technology tags of the SD EU houses were checked for any frequencies. The biggest variety of technologies was used to secure a comfortable indoor temperature. The three technologies used most frequently in the SD EU context to achieve temperature comfort by heating or cooling are illustrated in figure 7. The structure shown here is based on the method used to structure the technology tags in the KP.

Like shown in figure 7, besides solar energy technologies, ventilation systems and strategies are most frequent in the SD houses, what makes them potentially interesting for projects like the above-mentioned Annex 68 "Indoor air quality design and control in low energy residential buildings". (link 2) For the Annex 68 case studies and facilities for field measurements are needed, like described by subtask 5: "field measurements and case studies". "The tests will include studies of new ventilation patterns in highly energy efficient residential buildings based on improved airtightness, increased insulation, use of materials, and possibly also new residential behaviour." (Annex 58, 2015).

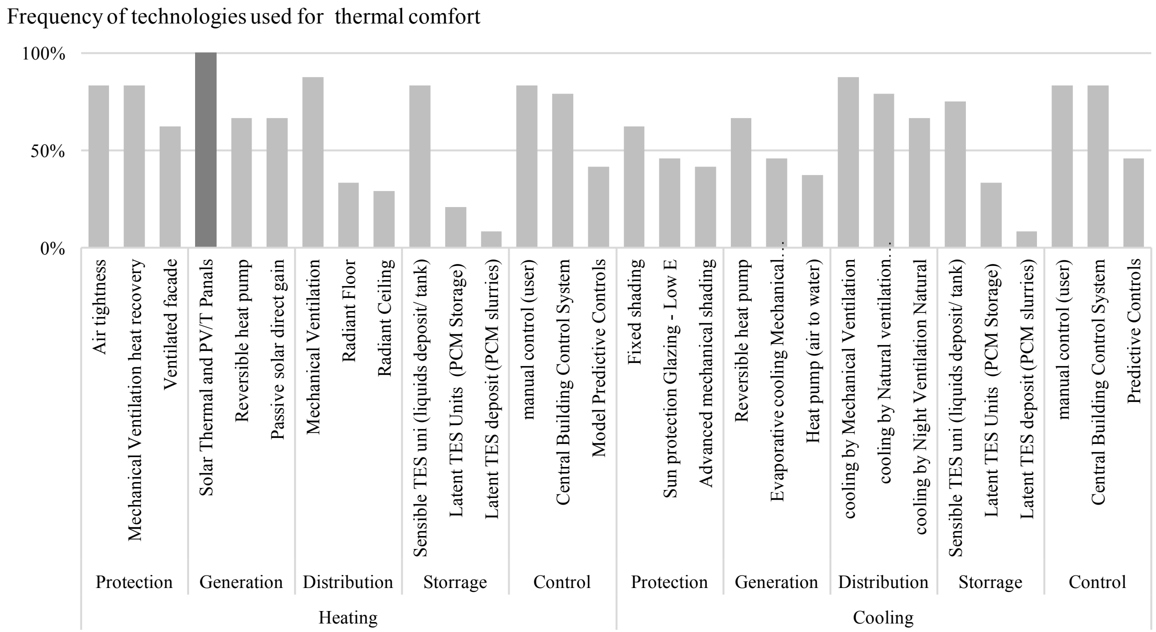

Fig. 7: Frequency of technologies used for temperature control in the Solar Decathlon Europe houses. Because of a lack of information, not all of the 56 SD EU houses could be analyzed and tagged properly. For this research, a total of 46 houses were analyzed.

Source: Wuppertal University; Hendel

The temporal distribution of solar technologies used in the past SD EU houses shows the function and the cooperation of the fact sheets and tags. The SD EU houses added an average of $6m^2$ of solar thermal systems to their building envelope (figure 8). Combined with the average installed size of $55m^2$ for the PV systems, this means that the SD houses had more area used for solar energy generation than they had for conditioned floor areas and therefor made the extra envelope area useful to deal with this stronger environmental influence. Also, the range of possible technologies that are photovoltaic, solar thermal or hybrid is to be expected significantly higher than in common buildings. Therefor the possibilities to test even experimental and innovative technical approached lies within the concept of the SD houses. That makes the SD houses even more interesting since many case studies now focus on innovative solar energy solutions.

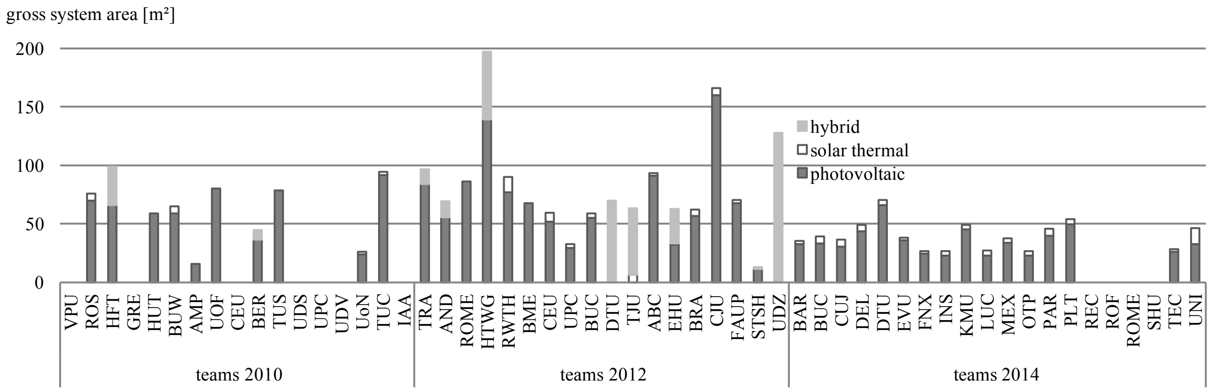

Fig. 8: Use and size of solar thermal, photovoltaic and hybrid systems of the SD EU houses.

Source: Wuppertal University; Hendel

Because the SD houses have a higher energy need for cooling, due to a stronger environmental influence and on the other hand they have a higher potential for solar energy generation, a further look into the data by using the

KP team fact sheets about the solar systems can give an insight of the common approaches. The solar thermal systems used by the SD EU houses are much smaller than the installed photovoltaic systems (figure 8). This is explained by the higher need for electric energy than in thermal energy. The heat generated by the solar thermal systems was usually used to provide domestic hot water. During all European competitions, there was simply no need to heat the buildings during the event, but to cool the building and therefore electric energy was mainly needed.

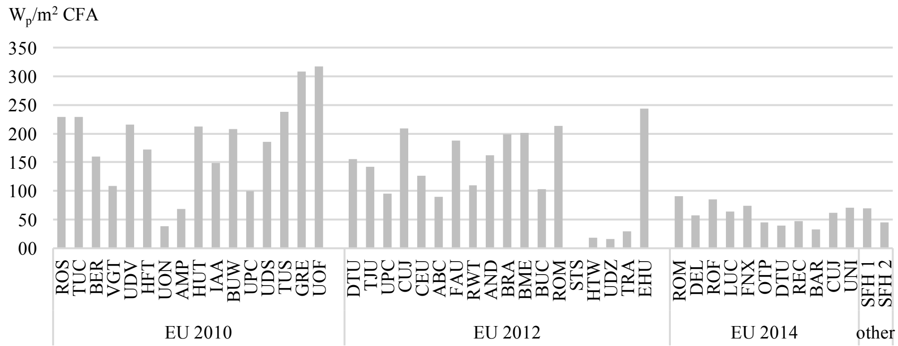

Fig. 9: Correlation of nominal peak power of the installed PV modules and the conditioned net floor area of the SD EU 2010, 2012 and 2014 houses.

Source: Wuppertal University; Hendel

The importance of solar power generation is reflected in the correlation between the installed power and the conditioned net floor area (figure 9). In the three European competitions, the mean ratio is $135W_p/m^2$ CFA. In comparison, the ratio for single family homes in a German research project (BMUB 2014) for plus-energy houses was $69W_p/m^2$, and for zero-energy buildings investigated in the IEA context (Voss, Musall, 2012) the ratio was only $45W_p/m^2$.

Although, the nominal power of the photovoltaic systems was limited to $15kW_P$ in 2010, $10kW_p$ in 2012 and $5kW_p$ in 2014 by the competition rules, the potential of solar energy generation is higher than in common buildings. Therefore, it is to be assumed that the houses could cover their energy demands by using solar energy only. This distinction makes them perfectly suitable for studies to evaluate the solar energy use in homes specially to secure indoor comfort during summer conditions. In that way, it is possible to study an energy supply for residential buildings exclusively from renewable energy sources, with all the difficulties and without the usual restrictions. Difficulties would be, for example, the time lag between energy production and energy demand. And because the SD houses are usually free standing and not shadowed they don´t have to deal with restrictions like seasonable shadowing.

4.3. optimization for future scientific use of the SD houses

For the analysis above, that showed the size of the SD houses and the extensive use of solar energy, the existing documentation of the SD EU houses was filtered by the KP tags and further scrutinized by using the information stored in the fact sheets. Due to a lack of quality and completeness of the existing documentation only 46 out of 56 SD EU houses could be tagged properly and used for this analysis. Also, the existing data cannot be used for a deeper analysis because of a lack of comparability and quality. For all future SDs the KP will secure the needed completeness and quality of the documentation.

Besides the achievement of a complete data set from future SD houses by applying the KP and by setting the standard of completeness based on the existing data, the KP will ask for more information (cf. KP). Because the SD houses are more exposed to environmental influences and highly equipped with innovative technologies not only the overview of the technologies used and their frequencies and trends of application, but also deeper insights in how they were applied would be interesting. In particular, the control strategies should be also documented to make a scientific use of the data possible. Interesting, for example, are control strategies to deal with hot summer climate and high indoor comfort expectations by only using the amount of energy produced by the installed PV systems.

In addition, building users have a significant influence on the building performance especially in small and highly energy efficient buildings. Users interfere with system controls, opening windows, running appliances or simply by the are present. Therefore, the user presence and behavior also should be a part of the future documentation. This would be needed to interpret and use the monitoring data. The houses are intensely monitored and publicly toured during the event. An event usually lasts 10 to 14 days. During that time, a documentation of the user behavior and the number of people inside the house should be possible without violating the privacy of any inhabitants.

5. Conclusion and Outlook

In building performance projects a lack of suitable case studies is a common obstacle. But the SD houses are particular suitable to serve as case studies in building performance projects. In the past, SD houses were already used for case study projects focusing on the whole building performance or the performance of components. However, because of insufficient documentation these SD house based research projects were only possible by researchers having a direct connection to the analyzed house, like being a team or SD organization member.

The implementation of the KP will significantly optimize the documentation of future SD houses to make them broadly useable for case study based research projects. The core value of the KP is that SD teams have to deliver all information asked in pre-structured templates, that ensures full data sets and absolute comparability of the data. This is the key to have a continuously growing pool of scientific relevant case studies. The KP serves as a documentation platform for the existing and future SD data. In principle, the documentation of the existing houses could be used to analyze the performance of certain building concepts and technical approaches, in particular, because the event monitoring data sets are also available. But the documentation of previous SD´s was not structured to meet scientific demands.

The research connected to the design and implementation of the KP led to a full SD EU dataset in the KP. The documentations of the SD US houses from 2009 to 2017 will follow within the next year. Also, the tags set up so far are addressing the topics "Technologies used" and "Materials" and further tags like "building shape and orientation" and "usage and location of the houses after the competition" will follow.

This paper is part of a research project evaluating the potential of the SD. The SD houses, the data generated within the competition and the competition itself have the potential to serve for more than just to be a public event to educate student teams and the general public. As illustrated here, the houses and their documentation can be profitably used for building performance case study research projects.

6. Acknowledgement

The project and the resulting online database were funded by the Federal Ministry of Economics and Energy by resolution of the German Bundestag.
The connection to the Annex 74 (Annex 74) and therefore a direct connection to SD organizers from past and present competitions, led to profound feedback that was fundamental to create the KP.

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