Solar Decathlon - New Ways of Construction for Decarbonised Buildings

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Abstract

For the international building competition Solar Decathlon Europe 2021/22, a renovation and extension of an existing building was developed with the aim of sustainable construction and minimal carbon footprint. Prefabricated timber elements are used for the construction, which were developed with the aim of long-term CO_2 sequestration and the separability and recycling of the components. The highly thermally insulated building envelope, passive solar gains and ventilation with heat recovery form the basis for covering the demand for heat and electricity through façade-integrated PVT collectors and a PV system on the roof. A novel storage system, which uses the weighting of the wooden ceilings for impact sound insulation, decouples generation and consumption.

A representative section of the design with a usable area of 60 m² was built for the competition. This article presents the concept, planning and construction of the building.

Keywords: PVT collector, building integration, thermal storage, demonstration, Solar Decathlon

1. Solar Decathlon

Solar Decathlon is an international student competition for architecture and energy (Bergische Universität Wuppertal, 2022). Highly efficient and self-supplied buildings are planned, built, operated and juried. At Solar Decathlon Europe 2021/22 (SDE21/22) the student competition was focused on urban context, for the first time. Sustainable building and living in cities were the aims that 18 teams of eleven countries had to find innovative solutions for. The concept for the developed high energy efficient and autarch operated buildings should then be transferable and replicable to other European cities. The transition of cities is seen as an important step towards a climate-friendly future. A sustainable transition always has to take place on several levels. This is why the contributions give answers to the ten disciplines in the decathlon – from architecture, solar energy, social awareness up to urban mobility.

In this case, sustainable building and living was seen with the eyes of resource saving, energy efficiency and social responsibility. Construction of the building shell was in consideration to the choice of materials, separability, carbon footprint, way of construction as well as to the quality, insulation and air tightness of the building shell. In terms of energy, topics like integrated energy generation, storage concepts, components of the energy system and their interaction and automation were discussed. These architectural and technical topics have then been embedded in a social context. New ways of building integration in its neighborhood, ownership structures and addressed groups of residents gave the social framework for the concept.

The SDE21/22 competition was divided into two parts – a design and a building part. The design challenge contained the renovation and extension of real existing buildings by consideration the mentioned points for sustainable building and living in cities before. Generating living space without sealing additional land was the aim of this challenge. Sustainable redensification of urban areas had to be planned interdisciplinary and integral with all trades involved.

In the building challenge, a demonstrative part, a small excerpt, of the planned residential building was planned as a self-standing unit. This demonstrator (House Demonstration Unit, HDU) could have up to 70 sqm living space and contained all necessary functions of living. This part had then to be constructed, prefabricated and

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assembled within only two weeks for the competition final in Wuppertal in June 2022. During three weeks in the final, the demonstration unit was operated and evaluated by a professional jury. Figure 1 and Figure 2 show the constructed demonstration unit (HDU) on site of the team X4S.

Figure 1: Assembled House DemonHDU elevation north-east

Figure 2: Assembled HDU elevation south-west

2. Given Situation and Objectives

As one of the 18 participating teams, the Biberach University of Applied Sciences took part in the SDE21/22 competition as “Team X4S” – the short form for “Extension for Sustainability”. By choosing one situation given by the organizers, the team of Biberach planned the renovation and addition of Café Ada – a two storey building from the Gründerzeit that is located in the Mirke quarter in Wuppertal, Germany. The cafés footprint is about 400 sqm and the building is used for cultural activities. Additionally, the adjacent outdoor area was also part of the competition to be included in the planning.

For the renovation and addition of Café Ada, the team X4S developed a holistic concept that also meets economic, social as well as urban integration requirements. The existing building should be renovated moderately (specific heating demand less than 50 kWh/m²) usable floor space) and the public use should remain. On top of these two floors, a four storey extension with roof garden is planned. Living space as well as community and co-working spaces are offered, see also Figure 3 and Figure 4. The roof garden provides also community space for urban farming, is used as rain retention in case of heavy precipitation events and is covered by a PV-roof. The building shell is carried oud in passive house quality. The roof and façade are used for energy generation to supply the whole building.

Figure 3: Modell of café Ada and its planned extention, elevation south-west

Figure 4: Modell of café Ada and its planned extention, elevation north-west

The entire solution excels in terms of sufficiency, efficiency, consistency and resilience. The extension of café Ada acts as a transferable example on how to change the built environment in order to achieve greater sustainability and address social and economic demands at the same time.

Densification solves urban issues like excessive land use, increased traffic due to spread-out cities or social isolation. The design focuses on residents who are interested in social participation. With different small and flexible floor plans, like it is shown in Figure 5, the building provides living space for one or two-person households as well as for small families.

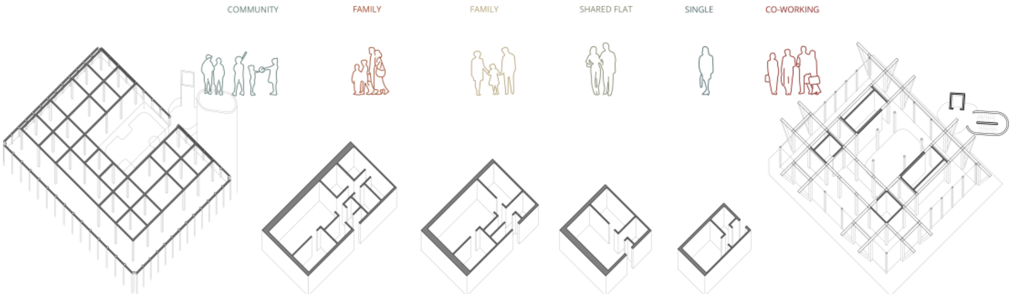

Figure 5: Different flats for different needs are part of the architeture

Cost-effective and fast to build constructions are achieved by solid timber elements which are developed with prefabrication of elements and modules, minimal loads by using solid wood constructions and separability to ensure reuse and recycling of the building materials. Fire protection is achieved with this solid wood construction without additional concrete parts or encapsulation.

The climate neutrality of the building is achieved through the use of renewable raw materials with low a percentage of grey energy, highly thermally insulated building envelope, the energy refurbishment of the existing building, heat recovery from the ventilation system and solar activated façades and roof surfaces. A consistent low-temperature concept and the use of the building’s mass as storage increase system efficiency. A grid friendly operation is enabled by storage systems in combination with an intelligent management system.

To make sustainability affordable, we employ existing efficient technologies integrated in a highly efficient and resilient system design. Reduced private in combination with huge communal spaces, multifunctional building elements like integration of ventilation systems or electrical distribution system and less technic but high efficient are just examples for this.

In terms of energy, the objectives are described in detail below:

- Reduction of energy consumption through the highly thermally insulated building envelope and heat recovery from ventilation systems
- Extensive renovation measures of the building envelope of the existing building
- Replacement of fossil fuels with heat pumps that draw their energy from renewable sources
- Use of solar radiation on façade and roof to generate electricity and heat
- Improvement of system efficiency of heat pumps through the use of PVT collectors and the consistent reduction of system temperatures for both heating (panel heating systems) and hot water production (decentralized fresh water stations)
- Thermal storage with minimal additional costs due to the activation of required building component layers.
- An open-source smart home system as an information system for the users of the building and for monitoring and automating the system.

3. Energy Concept and Solar System

In order to minimise the carbon footprint with measures in and on the building, a energy concept was developed that is shown schematically in Figure 6. Building-integrated solar systems for electricity and heat form the basis of the system.

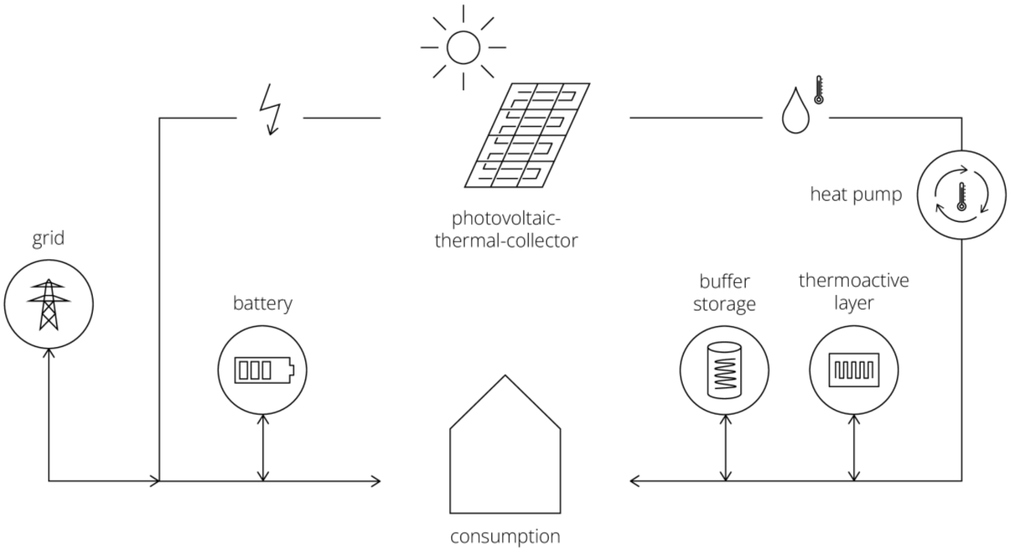

Figure 6: Energy concept with solar systems for both electricity and heat. Load management together with battery and thermal storage enables high solar fraction and grid-friendly operation

Semi-transparent PV modules on the roof are used to generate electricity. For the building design, the extension of café Ada semi-transparent glass-in-glass modules were chosen. In the demonstration unit, newly developed tubular thin-film PV modules were used, see Figure 7 and Figure 8. Due to the distance between the tubes, the tubular modules have a lower yield in relation to the gross area than closed modules. On the other hand, the solar yield is more even and higher in the daily sum due to the more favourable angle of irradiation.

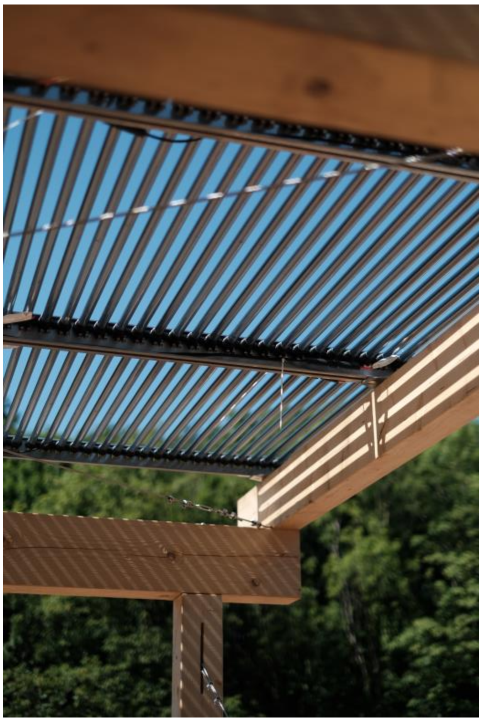

Figure 7: Air- and water-permeable solar roof with solar tubes for energy generation

Figure 8: Extensive and intensive greening is possible under the solar roof.

A special feature is that the drainage of the solar module takes place on the underlying retention roof. This relieves the load on the public drainage system during heavy rainfall events.

Since the energy demand of the building increases with the number of storeys, but the roof area is limited, the façade is also used to generate solar energy. As a result, the solar yield scales with increasing floor space.

Vertically installed uncovered PVT collectors are used. A challenge in technical and design terms was the integration of marketable PVT modules into the façade. The solution developed in cooperation between architecture, building physics, timber construction and energy technology is shown in Figure 9 and Figure 10. Important aspects were the rear (passive) ventilation of the modules, the removal of condensation during the heating period and the reduction of penetrations in the façade for a durable construction.

Figure 9: Eastern and southern facade of the HDU are solar activated with PVT modules

Figure 10: The facade integration of the PVT modules has been developed interdisciplinary

The thermal system, see Figure 11 for a schematic representation, uses the PVT collectors in the façade as a heat source for a power-controlled heat pump. The power control is used to adapt the operation to the electrical and thermal solar yield. This improves the COP of the system, especially during the heating season.

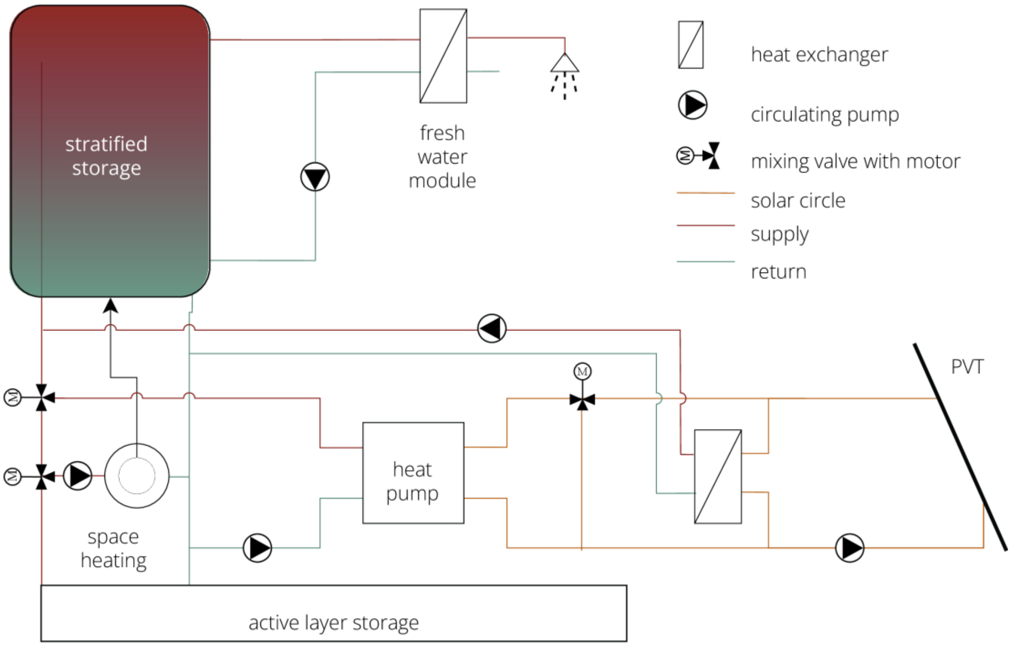

Figure 11: Thermal system with PVT collectors integrated in the facade, heat pump buffer storage and active layer storage.

Two thermal storages help to realise this efficient mode of operation: A buffer storage tank with two thermal zones stores heat for surface heating up to 35°C and for hot water preparation at 50°C. The mass of the impact sound insulation serves as a second storage. This is operated in the temperature range from 20°C to 35°C. Due to its dual use as impact sound insulation and as a thermal storage as well as its simple construction, it can be realised very cost-effectively. Another important feature is that this storage scales with the usable area and thus with the required heating energy. This combined storage system is the basis for decoupling the heat demand from the solar yield. classic underfloor heating system installed below the flooring is used for the heat output to the room.

Hot water is provided via decentralised fresh water stations installed in all the flats. This achieves hygienic hot water preparation at low temperatures and without hot water circulation. Heat recovery from the shower water can also be integrated very efficiently into this system. The associated device is integrated into the drainage channel of the shower.

The electrical system uses a battery constructed from common Li-ion cells of the type 18650 as storage. These are found in notebooks, e-bikes, etc. The modular concept of the battery allows the use of second-life cells and the exchange of individual cells. Due to the design of the stack, high charging and discharging currents are possible even without welding. This is the basis for separability at cell level.

Battery inverters available on the market have high efficiencies of over 90 % at nominal power. In the partial load range, however, the efficiency drops significantly. Now this load range is the dominant one in buildings. Against this background, an AC-DC hybrid system was developed. Electrical devices that generate heat at high power are supplied with alternating current (AC) via the battery inverter. Appliances with loads up to about 100 W are supplied with direct current (DC) directly from the battery. For this purpose, a component-integrated DC distribution system was realised as a prototype.

4. Student's Team X4S

The creation of sustainable building and living demands the participation of all involved trades from the beginning of the planning. Therefore, the team X4S was an interdisciplinary team with team members of architecture, energy engineering, project management and civil engineering (Hochschule Biberach, 2022). Students and professors contribute with their special expertise. Normally, the collaboration of students from different disciplines is not practiced at university. Therefore, it was a great challenge to develop together an integral and sustainable solution for the competition entry. In joint interdisciplinary meetings, the awareness and understanding for the other disciplines raised slowly. An exciting and exhausting process over more than two years bonded all members to the team X4S. So, it was possible to consider special requirements and boundary conditions of all trades.

Figure 12: Interdisciplinary collaboration of students and professors

A close cooperation between students and professors was also important as it is at small and familiar universities like Biberach. By integration the topics of the SDE into the courses, students could make basic research, evaluation and simulations. At the Biberach University, even new, interdisciplinary courses were created for the preparation of the competition entry in order to enable joint work. With the support of the university administration, study regulations were adapted. So, professors and students could invest more time and energy during their everyday university life to work on the project. One outcome of this process is that team members have gained a deeper understanding of unknown but important aspects from other disciplines. This cross-disciplinary knowledge is necessary for the construction and refurbishment of buildings for a carbon-neutral future.

The implementation of the planning into a real building was achieved with the support of the carpentry training center of Biberach. The team X4S did all executive work, prefabrication and assembly on his own, see also Figure 13 and Figure 14. A large number of the students involved were trained craftsmen. Therefore, there was no need to award contracts to specialist companies for the execution of the planned demonstration unit. This linking of planning and execution supported the learning process in a particular way.

Figure 13: Some difficult connections were solved during prefabrication.

Figure 14: The students did the whole prefabrication and assembly by their own.

5. Conclusions

The international Solar Decathlon competition provides an impulse for the conception and realisation of sustainable buildings with a high proportion of solar coverage by student teams. The example of the team from Biberach University of Applied Sciences shows the importance of interdisciplinary teams for sustainable construction and CO_2-free operation of buildings. Beyond the competition, the buildings can be used for research topics such as active-layer storage and façade-integrated PVT collectors.

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6. References

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