Published in: Proceedings of the 8th International Conference on Sustainable Energy Technologies, Aachen, Germany, 31. August- 3. September 2009

Solar Decathlon Europe 2010

Sebastian Fiedler[1], Antoine Dalibard[2], Ursula Eicker[2], Jan Cremers[1]

[1]Faculty of Architecture and Design
[2]zafh.net
Hochschule für Technik Stuttgart, Germany
Schellingstraße 24, 70174 Stuttgart
Tel.: +49 711 8926 2876, Fax.: +49 711 8926 2698
sebastian.fiedler@hft-stuttgart.de
http://www.sdeurope.de

ABSTRACT: The Solar Decathlon Europe is an international competition for universities from all over the world to design and build a self-sufficient home, grid-connected, using solar energy as the only energy source and equipped with technologies that permit maximum energy efficiency.
An interdisciplinary team of architects, interior architects, structural engineers and building physicians at the Hochschule für Technik Stuttgart accepted the challenge and is working on the design of the building since October 2008. The basic idea of our design is to use traditional means of dealing with the climate in hot and arid zones and to combine them with new technologies. Thermal mass, sun shading and evaporative cooling will help to achieve a comfortable indoor climate with passive means. The key element of our passive cooling concept is a new building component that we call “energy tower”, which is also an important feature of the interior design. In addition night cooling via sky radiation and evaporation is used to discharge PCM material. Active cooling is supplied by a reversible heat pump powered by photovoltaics.

Keywords: Solar Decathlon Europe, passive cooling, evaporative cooling

1. INTRODUCTION

The Solar Decathlon Europe is a great chance for students and schools of architecture to gain experience, to exchange ideas and to promote the concerns of energy-efficient and sustainable building. This paper aims to introduce the competition and to present the design and energy concept of our contribution.

2. SOLAR DECATHLON EUROPE

2.1 The competition

In the Solar Decathlon Europe, 20 different universities from all over the world compete to design a home powered only by sun energy and to build it until June 2010. Then the house of each team will be presented to the public in Madrid and the winner will be chosen.

2.2 History of the competition

In the years 2003, 2005 and 2007 the Solar Decathlon competition was organised by the US Department of Energy (DOE) and carried out in Washington D.C. After the very respected victory of the TU Darmstadt at Solar Decathlon 2007 in the USA, the competition will be carried out now for the first time also in Europe, organized by the Spanish Ministry of Housing in cooperation with the US Department of Energy (DOE).

Fig. 1: Solar Decathlon 2007 in Washington D.C.
(Credit: Kaye Evans-Lutterodt/Solar Decathlon)

2.3 10 disciplines

In the competition the houses will undergo 10 contests [1]:

Table I: Contests and Scoring

Architecture	130
Engineering and Construction	80
Solar Systems	80
Electrical Energy Balance	130
Comfort Conditions	130
Appliances	80
Communications and Social Awareness	80
Industrialization and Market Viability	80
Innovation	80
Sustainability	130
	1.000

2.4 Objectives of the competition

The main objectives of the competition are [1]:

1. To generate knowledge on the industrialisation and sustainability of the homes, increasing suitable scientific benefits, as well as, the dissemination of the knowledge.
2. To make both students and the general public aware of the environmental and sustainability issues, especially of the responsible use of energy and natural resources, promoting the use of the renewable energies.
3. To maximise the publicity of the event by taking advantage of the competition's characteristics and potential to achieve the maximum media coverage and public information.

3. DESIGN CONCEPT

3.1 Basic concept

The design is based on architectural and energetic considerations. The starting point is a compact and highly insulated volume, with a small surface to volume ratio. The volume is segmented into four modules, which are positioned with interspaces between them.

Fig. 2: Model Team HFT Stuttgart

These gaps are used for lighting, ventilation, pre-heating in winter and passive cooling in summer. One of these gaps is higher than the others, containing the "energy tower". Based on traditional principles of climate control, the energy tower is a key element for the energy concept (see part 3) as well as for the outer appearance of the building and the interior space (fig. 3).

The modules and the gaps are bound together by the building envelope, which is covered in large areas with photovoltaic elements.

3.2 Zoning

The interior shows a clear zoning. In north-south direction the terrace, the living area and the dining area are marked by the gaps, but can be used as one big space also. This is especially important for the two dinners we have to invite our neighbours in the solar village to in June 2010. The more private working and sleeping area is separated by the volume of the energy tower. In east-west direction each area is accompanied by a serving zone (kitchen, entrance and facilities, bath).

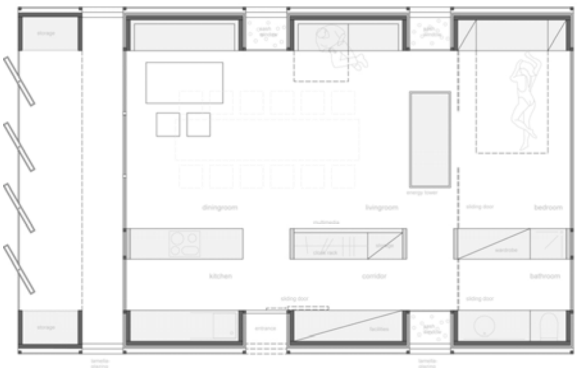

Fig. 3: Floor Plan (North to the right)

3.3 Modularity

The modular design of the building does not only facilitate the transport to and the assembly in Madrid, but also allows thinking about a modular building system for different requirements. Using the same basic modules it is possible to create living and working space for singles, couples, families or apartment-sharing communities in detached and semi-detached as well as in multi-family houses.

3. ENERGY CONCEPT

3.1 Basic concept

The basic idea of our design is to use traditional means of dealing with the climate in hot and arid zones and to combine them with new technologies. Thermal mass, sun shading and evaporative cooling will help to achieve a comfortable indoor climate with passive means. The key element of our passive cooling concept is a new building component that we call “energy tower”, which is also an important feature of the interior design. In addition night cooling via sky radiation and evaporation is used to discharge PCM material. Active cooling is supplied by a reversible heat pump powered by photovoltaics.

Since the competition occurs in June in a Southern Europe country, the most challenging part is to satisfy the comfort level in cooling mode, which will be the focus of this study.

3.2 Passive cooling systems

The energy tower supplies passively part of the ventilation and cooling needs by evaporative cooling (fig.4) when the ambient conditions are not extreme (not too hot, not too humid).

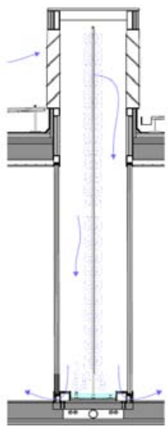

Fig. 4: Energy tower with passive downdraught cooling

Free cooling operates in moderate climate conditions and/or at night by letting the air flow through the openings in the gaps (fig. 5).

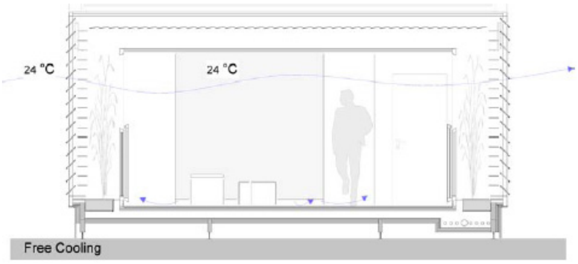

Fig. 5: Free cooling

3.3 Low energy night cooling systems

During the day, the PCM ceiling uses the latent heat of the PCM to store the heat and maintain the room temperature around the melting temperature (21-23°C). During the night, the PCM ceiling is actively regenerated using cold water from the night radiative cooling system on the roof (see fig. 6 and part 4.2). The cold water is stored in a cold storage and used during the day to activate the radiant floor.

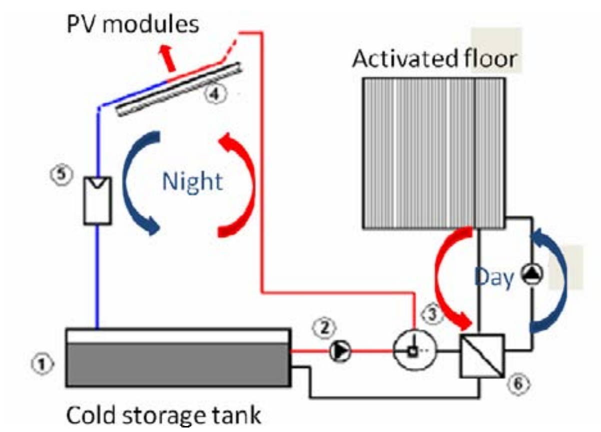

Fig. 6: Night sky radiation cooling system

The conventional ventilation system (active) is equipped with a heat recovery system between the return air and the supply air for winter and summer. Additionally an indirect evaporative cooling device enhances the cooling capacity through ventilation in summer.

3.4 Back-up cooling system

When the passive or the low energy cooling systems can not cover the demand, the reversible heat pump removes heat from the radiant activated floor to cool down the house. The choice of an electrical solution for the back-up is due mainly to the lack of thermally driven chillers in the range of small power and the lack of space available for the equipments (solar collectors, heat rejection devices,…). Therefore, the façades and the roof will be covered with PV modules in order to provide the electricity needs of the house and inject the rest into the grid. A classic solar thermal system will provide the domestic hot water needs of the building.

3.5 Control strategy

Once we know all the components able to meet part of the cooling demand of the house, one needs to define the order of use of these elements in order to meet the required cooling demand. The passive technologies will be used with the highest priority and then the technologies that require low parasitical energy will have the priority. Table 2 shows the priority given for each subsystem in the control strategy.

Table 2 Control strategy of the energy concept

Priority	Subsystems
1	PCM ceiling
2	Energy tower (if possible)
3	Free cooling
4	Night cooling / activated floor
5	Indirect evaporative cooling
6	Reversible heat pump

4. PLANNING RESULTS

4.1 Thermal building simulation

The dynamic thermal simulation of the house in competition conditions has been done using TRNSYS [2]. The meteorological data of the city-centre of Madrid have been generated with Meteonorm [3].

The maximum cooling load is 2.5 kW and the mean daily cooling energy to be removed is around 9-10 kWh/day. Figure 7 shows the cooling load distribution for the month of June.

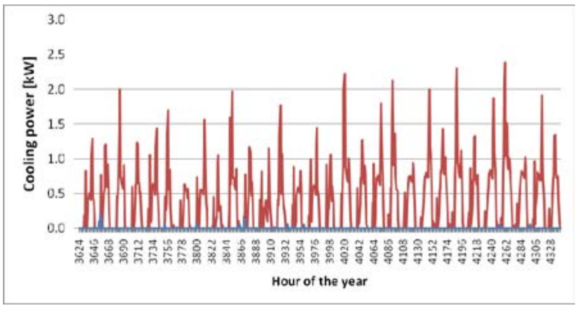

Fig. 7: Cooling load distribution (June)

4.2 Night sky radiative cooling system

Radiative cooling is based on the heat loss by long-wave radiation emission from a body towards another body of lower temperature, which plays the role of a heat sink. In the case of buildings the cooled body is the building surface and the heat sink is the sky (since the sky temperature is lower), especially during night, than the temperatures of most of the objects upon earth. Sky temperature during summer nights can be <0°C, with clear summer night sky conditions even sky-temperatures of -10°C could be achieved [4].

The radiative cooling system of the solar house is shown in figure 6 and has been simulated during June using the cooling loads of the thermal building simulation. A simulation model has been developed by Beck [5] and implemented in INSEL [6] during the planning phase of the solar house of the Technical University of Darmstadt, winner of the competition Solar Decathlon USA in 2007 [7-8]. Figure 8 shows the mean cooling energy per night as a function of the tank volume and mass flow rate used.

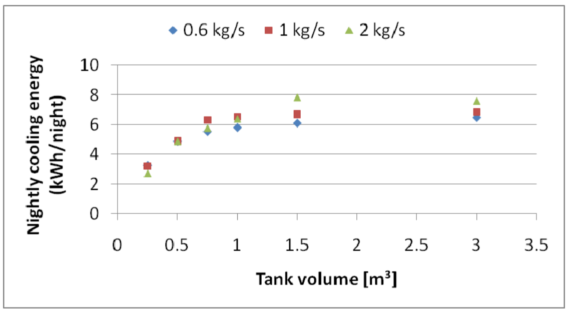

Fig. 8: Radiative cooling system - Nightly cooling energy

The tank volume has to be in the range of 0.8 - 1 m³ in order to bring significant cooling energy (6-7 kWh/night). The cooling capacity of the system is not due only to the radiative exchange between the water and the cold sky since evaporation and convection processes occur at the surface of the water film flowing on the PV modules (Table 3).

Table 3: Specific cooling power of different heat transfer processes (tank volume 1m³, mass flow rate 1 kg/s)

Total mean specific cooling power (W/m²)	Mean specific cooling power due to radiation (W/m²)	Mean specific cooling power due to convection (W/m²)	Mean specific cooling power due to evaporation (W/m²)
41.1	47.5	-15.1	8.7

The temperature in the tank can reach low values (10-15°C) at the end of the night if the sky is clear. Hence, the evaporation does not contribute to the cooling effect significantly since the water flowing is colder than the ambient air. For the same reason, free and forced convective processes contribute most of the time to heat-up the water instead of cooling it (negative value).

Another point of importance is the water consumption since no connection with the water grid is allowed during the contest and the house has to be stand-alone. The water consumption through the evaporation has been calculated to be 3.3 kg / night, which is reasonable if we consider the size of the tank.

4.3 Typical cases for the competition

We consider now the power balance of two cases taken from the building simulation results. The first one is a moderate summer morning with a temperature of 23-25°C and a relative humidity around 30-35%. The second situation studied is the extreme case of a hot summer afternoon (high internal gains, ambient temperature of 30-32°C and relative humidity of 50-55%).

4.3.1 Moderate summer morning

The cooling load of the house is around 1 kW. According to the control strategy defined previously, we first consider the passive technologies. The contribution of the energy tower is estimated by considering the maximal amount of humidity that we are allowed to introduce into the house if we want to respect the comfort level (22-24°C and 40-55% relative humidity). This corresponds to approximately 0.5 kW (considering ACH = 2). The PCM ceiling can easily handle the rest of the load (see fig. 9).

4.3.2 Hot summer afternoon

In this extreme case, the cooling load of the house is 2.5 kW. Given the ambient conditions, no more humidification is possible and the wind tower cannot be used. The PCM ceiling can absorb 1.4 kW of the cooling load, the activated floor around 1 kW (55 m² floor area) and the indirect evaporative cooling the rest (fig. 6).

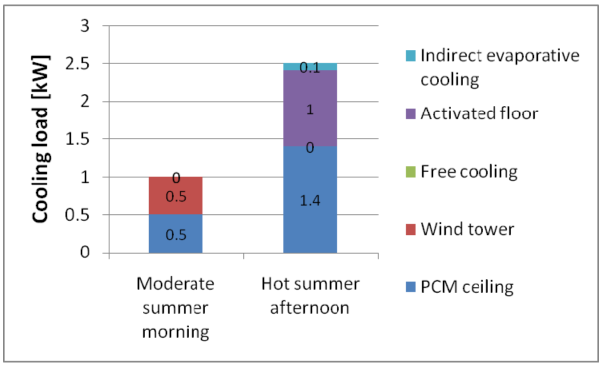

Fig. 9: Typical cases for the competition

5. CONCLUSION

The paper summarizes the design and simulation studies of a building, which has to be completely autonomous in its energy production. The main features are passive and active cooling systems based on evaporative and radiative cooling systems as well as on reversible heat pumps supplied by photovoltaic electricity.

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APPENDIX

Apart from the Team HFT Stuttgart three other teams from German universities participate in the competition. To give an idea of the variety of approaches in the competition, their concepts are described briefly.

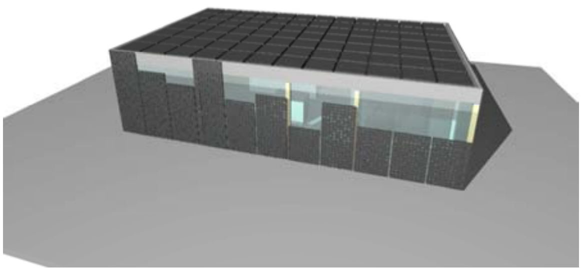
Team Wuppertal (Bergische Universität Wuppertal)

Two walls and a load-bearing waling build a point symmetric structure. The building is divided in two by opacity and transparency. The free interior builds, through a transparent façade, an almost seamless change-over between the two half open terraces on each side.

Team Living EQUIA (Hochschule für Technik und Wirtschaft, Universität der Künste and Beuth Hochschule, Berlin)

The simple main body of Living EQUIA's house is designed with two light axes running in a north-south and east-west direction. They open up the body of the living space and lend the house a sense of alignment with the four points of the compass and they also emphasise the link between the structure and the sun.

Team IKARUS (Hochschule für angewandte Wissenschaften, Fachhochschule Rosenheim)



The conception of Rosenheim SDE project focuses on flexibility in exterior and interior design. Flexible facade systems determine the outer appearance and underline the interior light conditions depending on sunlight. Modular building gives the opportunity to enlarge living space through components designed for fast and intelligent transport and construction.