

Chapter 5

Small Plus-Energy Buildings, Innovative Technologies

The Prototype-Building home⁺ of HFT Stuttgart

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Abstract A case study of innovative materials and sustainable design. Home⁺ is the result of an interdisciplinary university team enrolled at the Solar Decathlon Europe 2010 competition (Cremers (2011), Cremers (2010), Cremers and Eicker (2010), Cremers and Palla (2011) and Fiedler (2009)). The concept combines modularity of inner spaces with an efficient energy system in which one key element is a ventilation tower, a traditional building element renewed by using new technologies.

5.1 Introduction

In the following we present the architectural and engineering design of our contribution to the Solar Decathlon Europe 2010. The University of Applied Sciences Stuttgart participated at this international competition for universities, which was held in June in Madrid. An interdisciplinary team of architects, interior designers, structural engineers and building physicists developed and built a small residential self-sufficient building prototype of 74 m² for 1 or 2 people which can provide more energy than it needs. The basic idea of the home⁺ design is to use traditional means of hot and arid zones and to combine them with new technologies, using solar energy as the only energy source and equipped with technologies that permit maximum energy efficiency. The first aim was to optimize home⁺ in the points of the architectural/bioclimate concept (ratio of volume to surface, orientation, natural lighting and ventilation, passive conditioning and solar protection) and the building structure (high thermal insulation, use ecological materials and thermal mass) through energetically and energy saving aspects. Solar systems such as photovoltaic and solar thermal, integrated in the design concept, adopt added functions like shading, cooling via night sky radiation and the aesthetic effect. By this means it is

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Figs. 5.1–5.2 Photographs of home⁺ during the competition in Madrid (Source Jan Cremers)

possible to minimize the heating and cooling demand. In the summer, during the day the phase change materials (PCM) integrated into the PCM ceiling are able to passively cover a part of the cooling demand and a 1200 litres tank is used to dissipate internal loads via a radiant floor in free cooling mode (Low energy cooling). Additionally, several active components are added to maintain comfort conditions during temperature peaks, such as a reversible heat pump which also uses the tank as a heat sink. At night, the PCM ceiling is passively regenerated through photovoltaic-thermal (PV/T) collectors on the roof that act as heat sink tanks. Electricity consumption for the HVAC systems is therefore reduced to a minimum and the electricity balance of the house is largely positive (surplus of 7500 kWh/year) for the climate of Madrid. The basic innovations of home⁺ are the ventilation tower, the photovoltaic-thermal collectors and also the multi-coloured PV modules (Figs. 5.1 and 5.2).

5.2 Design 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. These climate 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 “ventilation tower”. Based on traditional principles of climate control, the ventilation tower is a key element for the energy concept as well as for the outer appearance of the building and the interior space. The modules and the gaps are bound together by the building envelope, which is covered in large areas with photovoltaic elements.

The modular design of the building facilitates not only transport to Madrid and assembly there, but also allows thinking about a modular building system with 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. Furthermore, it allows this modularity to adjust home⁺ into other climate conditions through adjustments of the climate gaps, especially the ventilation tower. We are aware that the ventilation tower, which is a key design feature of home⁺, is a very specific measure for a climate like Madrid. In this case, the tower cools the air down by evaporation. For example, in coast areas, instead of the tower there can be wind turbines and in colder areas it can be a hot water tank or a chimney.

The interior shows a clear zoning. Each of the modules has its own function beginning in north-south direction with; the terrace, the living area and the dining area. The different functions are marked by the gaps, but can be used as one big space also. This is especially important for the two dinners we invited our neighbours to in the solar village in June 2010. The more private working and sleeping area is separated by the volume of the ventilation tower. In east direction each area is accompanied by a serving zone (kitchen, entrance and facilities, bath); while the west side offers built-in storage zones. Therefore the building receives a clear structure in the north-south direction. East and west facades are as closed as

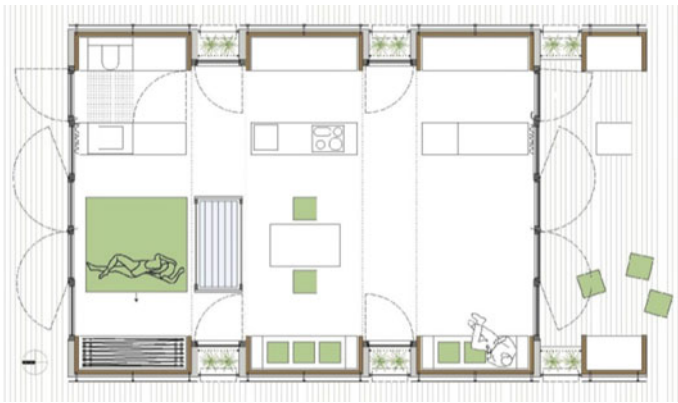


Fig. 5.3 Floor Plan [North to the left] (Source HFT Stuttgart)

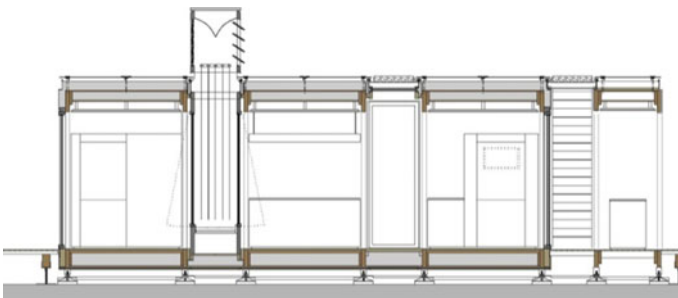


Fig. 5.4 Longitudinal Section (Source HFT Stuttgart)

possible (excepted the gaps) in opposition to the north and south facades where the solar irradiation is controllable. While the steep summer sun is kept out by a porch, the flat winter sun can enter deep into the house (Figs. 5.3 and 5.4).

5.3 Energy 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 “ventilation tower” (VT), which is also an important feature of the interior design. In addition night cooling via sky radiation and evaporation is used to discharge Phase Change Material (PCM) and support a radiative cooling floor. Active cooling is supplied by a reversible heat pump powered by a photovoltaic system. Since the building was designed for the hot summer in Madrid, most of the challenges arise in the cooling methods of the system. This study makes an emphasis in this specific area (Fig. 5.5).

5.3.1 Innovative PV Modules

For electricity generation, a large PV system of 12.5 kWp is installed on the roof on both west and east façades. Each façade is completely covered with 7 polycrystalline PV-Modules (3 kWp each) except for the gaps. On the roof, two different

Fig. 5.5 Interaction between Architecture and Engineering
(Source HFT Stuttgart)

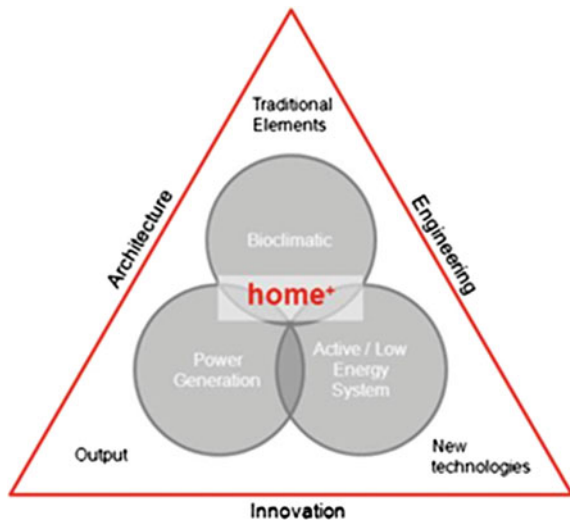


Fig. 5.6 Pictures of home⁺ during the competition in Madrid (Source Jan Cremers)



types of modules are installed; 12 small polycrystalline PV-Modules (1.5 kWp) are located on the east and west sides and 12 monocrystalline PV/T modules (photovoltaic/thermal collectors) (5 kWp) in the middle of the roof.

The innovation in this system is that, within the polycrystalline PV glass/glass modules, two different solar cells are combined and integrated. The reason for applying two different types of solar cells for roof and façades is a matter of design. Whereas the multicolour cells on the façade are an important design feature of our house, the monocrystalline cells on the roof have been selected to provide a maximum of power output per roof area. To link the two areas, we have introduced a new way to combine differently coloured cells in a dot-like pattern to achieve a transitional effect from one to the other area: the façade modules will turn with their colours gold and bronze around the edge, then becoming black with the monocrystalline modules in the middle of the roof (Fig. 5.6).

5.3.2 *Passive Cooling System and Heating via Ventilation*

In such a highly insulated building, control of the air supply by ventilation plays a decisive role. The segmentation of the house into climate gaps and modules makes it possible to use the glass-covered gaps for natural lighting and ventilation. In order to get the best results in energy consumption, air quality, air temperature and handling through the different seasons, the building will have 3 phases of passive ventilation, which are as follows:

- **Air Preheating** will be used when the ambient temperature is between 15 and 21 °C. Especially on sunny winter days it will help to heat the air in a passive way. The plants in these gaps humidify the air by evapo-transpiration which improves the air quality.
- **Cross Ventilation** operates in moderate climate conditions when the ambient temperature is between 18 and 24 °C; during the day and/or at night the air flows

through the totally opened gaps, thereby allowing a high air exchange through cross-ventilation. On hot summer days this is also used at night to cool down the mass of the building in a passive way.

- The **Ventilation Tower**, a new building component, which depicts the traditional tower ventilation in desert areas. The height and the orientation of the VT results from the prevalent wind flow. Statistics have shown that the wind direction comes typically from the south or the north. So we have the opportunity to catch the wind from both sides. The middle part of this gap has the function to ventilate and cool down the interior air without mechanical effort when ambient conditions are favourable. When the wind speed is high enough, the ambient air is caught by the tower, cooled through downdraught evaporative process and supplied to the building through the casement window at their basement. The areas left and right of it are used as Solar Chimneys (SC), to expel the exhausted air. On the inside of these glazed gaps are installed absorber plates to absorb solar radiation. They warm up and radiate heat to the air inside the SC. This warm air will then extract the interior exhausted air and transport it to the outside. This effect is caused by thermal lift and the wind pressure above the VT. Through the orientation, the air inside the SC is heated up all day long (Fig. 5.7).

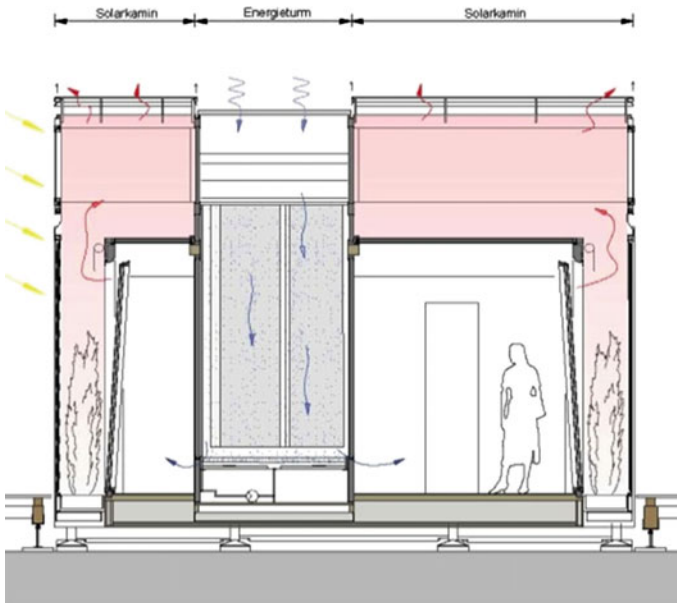


Fig. 5.7 Transversal section through the ventilation tower (Source HFT Stuttgart)

5.3.3 Low Energy Cooling Systems

The best way to avoid temperature peaks during the day is to use thermal mass. During the day, the PCM ceiling uses the latent heat of the PCM to store the heat and maintain 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 towards the clear night sky; the PV/T collectors. Radiative cooling is based on heat loss over long-wave radiation emission from one body towards another body of lower temperature, which acts as a heat sink. In our case, the cooled body is the PV/T module 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. The cold water is stored in a cold storage and used during the day to activate the radiant floor. Hence, the hybrid photovoltaic and thermal modules have two main functions: generate electricity (all year long during the day) and to regenerate both heat sink tank and PCM ceiling during the night (summer). In this way it is possible to use the valuable areas on the roof in a double way for a maximum output. The third possible mode, the cooling of the PV-cells during the day and generation of hot water is not under consideration in our concept.

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 (Figs. 5.8, 5.9, 5.10, 5.11, 5.12 and 5.13).



Figs. 5.8–5.10 Principle of PV/T collectors on the roof and PCM ceiling (Source HFT Stuttgart)

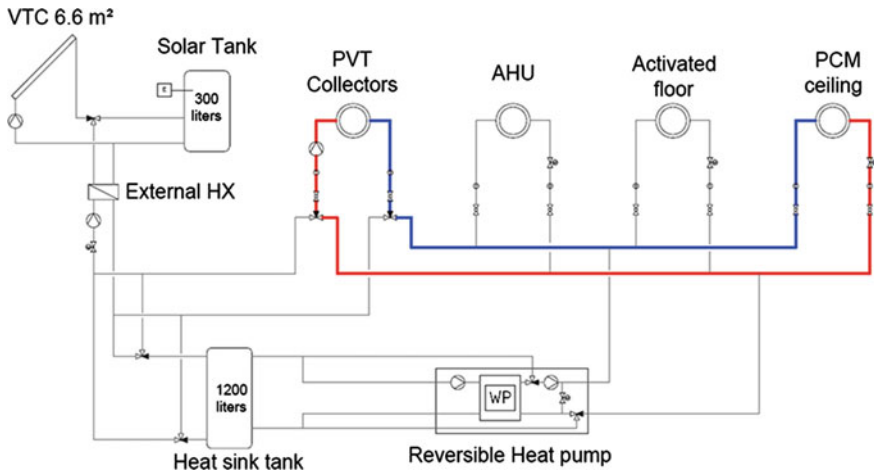


Fig. 5.11 Hydraulic scheme of summer night PV/T collectors and PCM ceiling [1st Period] (Source HFT Stuttgart)

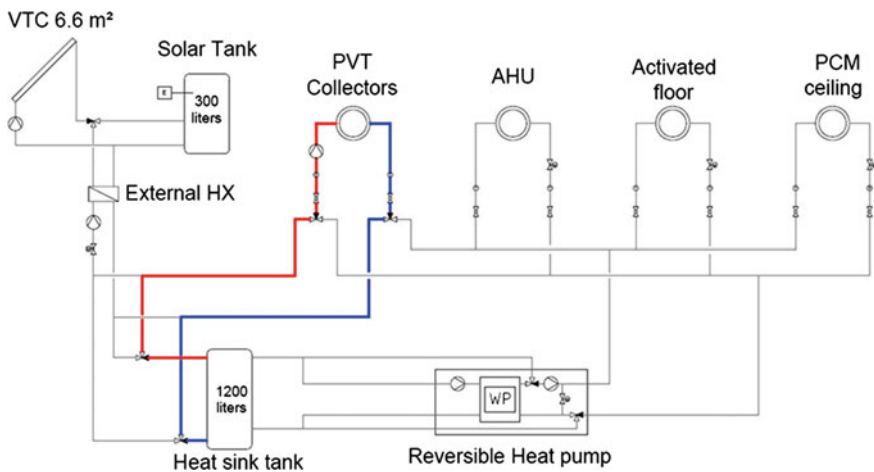


Fig. 5.12 Hydraulic scheme of summer night PVT collectors and heat sink tank [2nd Period] (Source HFT Stuttgart)

5.3.4 Back-up Cooling System

In order to satisfy domestic hot water, heating, and cooling demands, several active components have to be added to the basic concept of maximizing passive solar means and effects. When the passive or the low energy cooling systems cannot 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

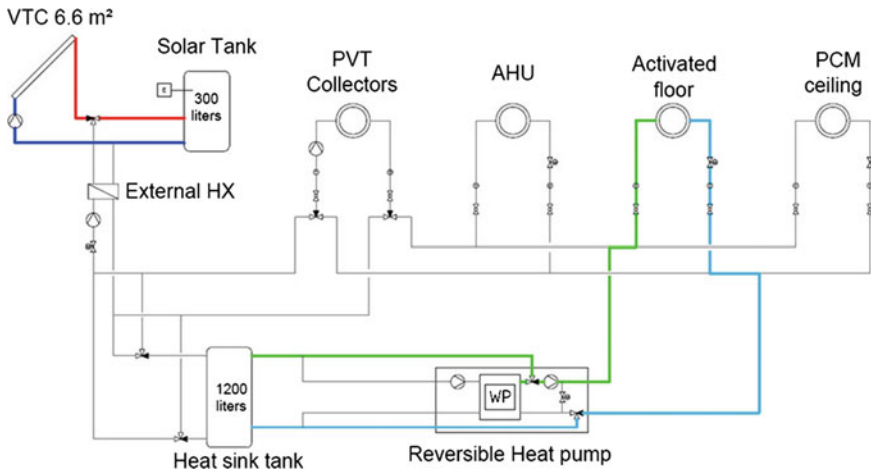


Fig. 5.13 Hydraulic scheme of summer free cooling at day (Source HFT Stuttgart)

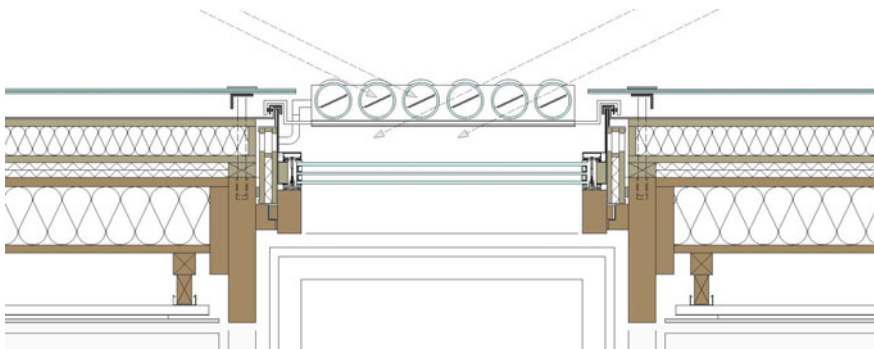


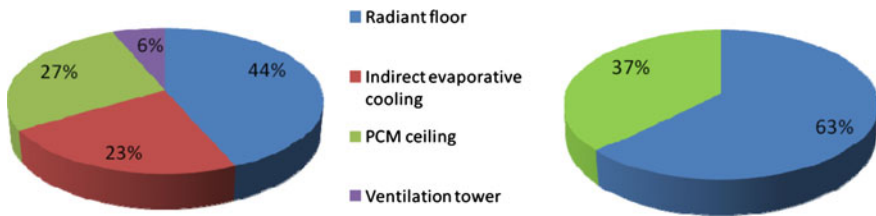
Fig. 5.14 Vacuum tube collectors with two functions: production of DHW and solar shading system (Source HFT Stuttgart)

due mainly to the lack of thermally driven chillers in the range of small power and the lack of space available for the equipment (solar collectors, heat rejection devices...). Therefore, the façades and the roof are 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 and to heat up the heat sink tank in winter when needed. The evacuated heat tubes are integrated in the building envelope as sun shading elements at the roof the glazed gaps (Fig. 5.14).

Table 5.1 Priority list in the control strategy

| Priority | Subsystem |
|----------|--|
| 1 | PCM ceiling |
| 2 | Ventilation tower (natural evaporative cooling, if possible) |
| 3 | Cross ventilation |
| 4 | Low energy cooling system (free cooling mode, if possible)/radiant floor |
| 5 | Indirect evaporative cooling |
| 6 | Reversible heat pump/radiant floor |

**Figs. 5.15–5.16** Distribution of cooling energy in the house and cooling energy distributed via the activated floor (*Source* HFT Stuttgart)

5.3.5 Control Strategy and Simulation Results

To control the complex hydraulic system described above, a sophisticated building automation is essential. 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. Passive technologies will be used with the highest priority and then the technologies that require low parasitical energy will have the priority. Table 5.1 shows the priority given for each subsystem in the control strategy.

The simulations for the HVAC have been done with TRNSYS (2006) for the climate in Madrid. The results show that the cooling demand is covered to 27 % by the PCM ceiling, 23 % by the indirect evaporative cooling and to 6 % completely passively by the ventilation tower. The radiant floor covers the rest about 44 %, this cooling energy has to be separated in the free cooling mode with low energy consumption and the reversible heat pump (Figs. 5.15 and 5.16).

5.4 Conclusion

Through the interdisciplinary work over two years it was possible to take under consideration all the aspects of the building beginning with the architecture, the building materials and the energy concept and minimizing the electricity demand of

cooling or heating purposes. The Solar Decathlon Europe 2010 was not only an improvement for the science but also for every team member.

Due to improvement of the whole concept of home⁺ it was possible to make an excellent 3rd place in the competition Solar Decathlon Europe 2010 and to take further prizes in five of the ten contests, for example first place in “Engineering and Construction” and Innovation” and second place in “Sustainability”.

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