The German Contribution to the Solar Decathlon Europe 2010 – A Comparison of Four Net Zero Energy Building Prototypes Monitored Under Equal Conditions

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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. Four teams from German universities took part in this challenging competition[1]:

- Team living EQUIA (HTW Berlin, Beuth-Hochschule Berlin, Universität der Künste Berlin)
- Team IKAROS Bavaria (FH Rosenheim)
- Team home+ (HFT Stuttgart)
- Team Wuppertal (Bergische Universität Wuppertal)

The final phase of the competition was held in Madrid in June 2010 and consisted of the assembly and exhibition of 17 houses. The houses have undergone 10 contests, in which several tasks had to be completed. The indoor air temperature had to be held between 23-25°C, the humidity between 40-55%, towels had to be washed and dried, dinners to be cooked and hot water draws from the shower to be taken etc [2]. In short: Everyday life has been simulated - and monitored. Throughout the contest week the electric generation, consumption and temporary generation-consumption correlation has been constantly measured. Now it is possible to compare the first operational experiences and monitored data of the four German contributions. The four houses built by the German teams participating in the Solar Decathlon Europe 2010 are net zero energy buildings (fig. 1). In Madrid they have been intensively monitored at the same place, the same time and with the same user profile. The strict terms and conditions of the competition assure the comparability of the monitored data and thus, of the concepts and strategies realized in the four prototype houses. The paper will thrive on this special circumstance and show a comparison of four innovative net zero energy building prototypes monitored under equal conditions.

Fig. 1 The Villa Solar in Madrid with the four German houses (Source: Jan Cremers)

1. Design Concepts and Strategies of the Four German Teams

1.1. Team living EQUIA, Berlin

The living EQUIA building reinterprets the archetype of a dwelling home with the means of solar architecture (fig. 2). The double pitch roof, inclined for optimal solar use, faces south. Two light axes open up the body, inviting the sun inside during the day, and letting the building radiate back into its environment at night. This idea of a compass emphasizes the communication of the corpus with the sun. The breamed wood shell provides a natural and sustainable protection and lets the solar systems blend in seemlessly. This unique integration of energy and architecture, along with innovative photovoltaic shading elements, convinced the competition jury to award the first price in the discipline 'Solar Systems'. Regarding the façade orientation the ratio of glass and high-insulate walls is energetically optimized.

The element construction method makes (dis)assembly easy. PV, Solar Thermal, a heat pump and a ventilation system with heat recovery are standard parts of the energy concept (fig. 3). Moreover technological innovations like vertical fins with integrated PV, loam wall elements with Phase Change Materials (PCM), a solar dehumidifier and a radiation surface perform energetic and climatic requirements. The entire energy necessary to operate the building is gathered from renewable sources. The gains of the PV system justify even a “plus-energy-building”, both in the competition setting in Madrid, as well as in other European climates and the buildings 'home-location': Berlin. [3]

Fig. 2: The Berlin house

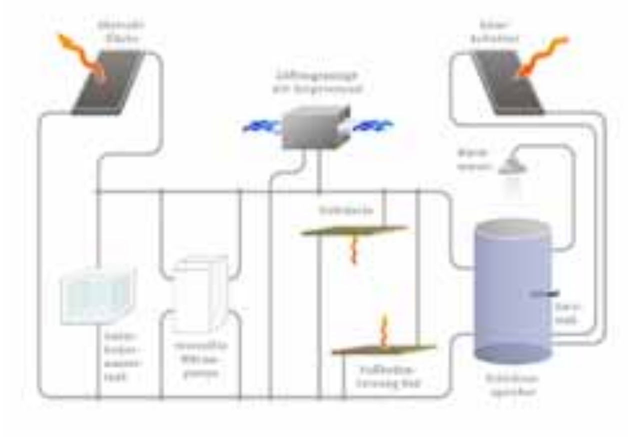

Fig. 3: Layout of the energy system

1.2. Team IKAROS Bavaria, Rosenheim

The Rosenheim Solar House is a plus-energy residential building (fig. 4). A newly developed facade system ("the zigzag facade“) and a multifunctional room concept represent the characteristic design features of the Rosenheim Solar House. At daytime the openings between the jags let sunlight fall into the building's interior, so that interesting light effects appear on the surfaces. As these "jags" let light enter into the room and also make it possible to look outside, the inhabitant is not separated from the environment.

The building's energy concept (fig. 5), which has been developed primarily with southern regions such as Madrid in mind, is based on an extremely good insulation, maximal air tightness and efficient sun protection. Assuming a normal use as a residential building, the consumption of electricity comes to 2,600 kWh/a (under competition conditions to 4,300 kWh/a), while the amount of power generated lies at a constant value of 16,000 kWh/a.

As for the climate concept of the building, we rely on active as well as passive/ hybrid systems. Triple-pane insulation, solar protection and sound insulation glazing are used for the building's south facade. During noon hours, when solar loads reach their maximum, the sun protection, which is retractable into the ground, can be moved right up to the eaves. Excessive solar loads are buffered through a PCM channel, which is operated with recirculation air. In the cool, clear night hours the tilted PV modules on the roof are sprayed with a continuous water film. Through radiation exchange with the clear night sky, convective heat emission into the ambient air as well as evaporation the water is cooled by up to 10 degrees Kelvin before being collected in an insulated reservoir. This reservoir is used for conditioning a heating/ cooling ceiling during daytime.

To use the building technology in a way that is as user-friendly and energy-efficient as possible, we have developed new regulation strategies. A control panel allows the user to regulate the building control systems (which are automated for the most part), to call up specific light scenes, execute multimedia applications and to view energy consumption and energy gain data. In addition, tips for optimizing energy consumption are available. [4]

Fig. 4: View to the north-east façade with the terrace (Source: Oliver Pausch)

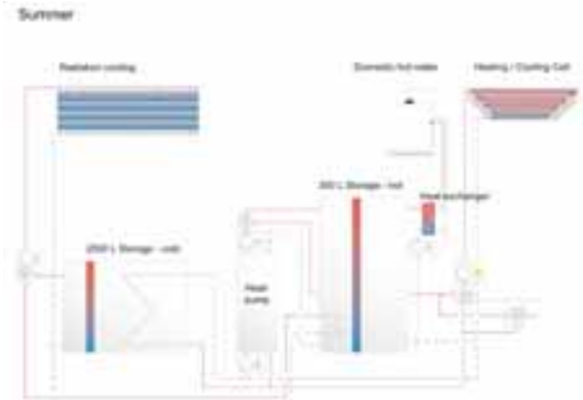

Fig. 5: Energy concept in cross section of building (Source: Johannes Maderspacher)

1.3. Team home$^+$, Stuttgart

The basic idea of the design (fig. 6) is to use traditional means of dealing with the climate in hot and arid zones and to combine them with new technologies. Thermal mass (PCM), sun shadings and evaporative cooling will help to achieve a comfortable indoor climate with passive means. An "energy tower" supplies passively part of the ventilation and cooling needs by evaporative cooling using the wind as driving force. Mechanical ventilation (AHU) with heat recovery and indirect evaporative cooling systems is used to reduce heat losses in winter and provide additional cooling in summer (fig. 7). Active cooling and heating is supplied through a radiant floor (30 m²) by a reversible heat pump (2.4 kW cooling) powered by photovoltaics (6 kW_p on the roof, 6 kW_p on the façades). In summer, a night radiative cooling system using hybrid PVT collectors (36 m²) regenerates the PCM ceiling (18 m²) and takes up the heat rejected from the reversible heat pump by cooling down the “heat sink tank” of 1.2 m^3. Measurements have shown a cooling capacity of the PVT collectors of 50-120 W/m^2 roof area depending on water and ambient temperature and weather (clouds).

If possible, a free cooling mode is run by pumping directly the cold water of the heat sink tank to the radiant floor. Dehumidification of the supply air can be done with the reversible heat pump through a fan coil by cooling the air below the dew point. Domestic hot water (DHW) needs are covered by vacuum tubes collectors (6.6 m²) which feed a 300 liter solar tank with electrical heater back-up. The collectors also provide shade in the area of the glazed gaps. In winter, when necessary, the solar thermal system provides heat to the heat sink tank in order to increase the heat pump efficiency. The PV system consists of around 66 m² of two-colour (Gold/Bronze, 13% cell eff.) polycrystalline cell modules on both east/west facades and parts of the roof and 33 m² of monocrystalline cells (17% cell eff.) for the PVT modules, also on the roof. The annual production is estimated to be 11.500 kWh exceeding the electric consumption of 4000 kWh by 7500 kWh (Madrid). [5]

Fig. 6: The solar activated power envelope of Stuttgart's home+ in Madrid (Source: Jan Cremers)

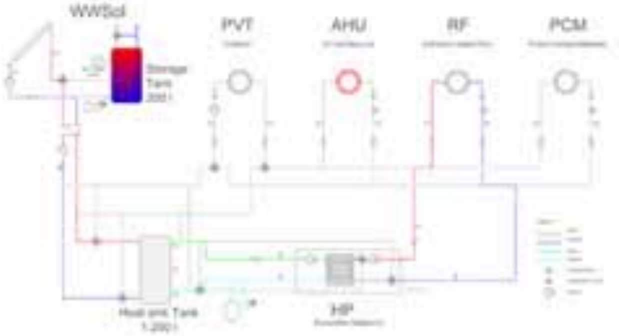

Fig. 7: Hydraulic scheme of Stuttgart's home+ (Source: SDE Team HFT Stuttgart)

1.4. Team Wuppertal

The building structure is the logical consequence of the idea of a flowing space (fig. 8). Load-bearing boards of laminated timber span 13 m between the two characteristic solar walls, thereby supporting the roof and the patio. The building footprint is 13 m x 23 m with a maximum height of 5.45 m and about 50 m^2 living area. The envelope design and construction follow the idea of a passive house using innovative elements such as the vacuum insulation of the timer beams. The three principles of passive cooling are consequently addressed to adjust the building to the Madrid climate: Reducing the summer solar load by efficient shading (the highly reflecting external curtain), extracting excess heat by stack effect night ventilation (automatic openings) and thermal mass (phase change material). The LED lighting ceiling with integrated motion sensors guarantees harmonic lighting during times without sufficient daylight availability.

27 modules form the 6.3 kW_p PV generator on the building roof. 18 modules are oriented towards the east with a slope of 3°; 9 modules are inclined west with 6° slope. The 115 square modules of the south oriented façade result in about 3.7 kW_p total generator power. The distinctive appearance of the solar wall is made by combining 75 modules of polycrystalline cells and 40 of mono crystalline cells. The system is connected to the grid by the switch box allowing the house to operate fully grid-connected as well as battery-buffered and occasionally stand-alone (fig. 9). Three inverters connect the solar power to the switch box as well as a back-up inverter and the grid. The switch box optimizes the use of a 7 kWh battery to preferably match the electricity demand of the house by its own solar energy generation and to optimize the performance with future smart grids.

Heart of the compact HVAC centre is a solar assisted air-to-air heat pump. It is able to switch between the heating to the cooling mode. An integrated heat exchanger allows more than 80% of the ventilation heat to be recovered (winter) and effective cooling of the supply air by evaporation of water in the exhaust air (summer). Air cooling and heating is assisted by a floor-mounted hydraulic system. 6 m² vacuum tube collectors are integrated part of the northern solar wall. Using solar gains for space heating favours a vertical arrangement although reducing summer solar gains.

The “home server” is the heart of the building automation system. It uses sensors, energy meters and user inputs to generate output signals for the actuators connected. Detailed monitoring os the system performance and energy flows allow the user to verify the building energy balance towards the aim of a net plus-energy home. Over 70% of the total building electricity demand of 3,400 kWh per year is met directly or indirectly - via battery during night - by solar power. A surplus of 9,000 kWh each year for the building in Madrid allows offsetting the buildings embodied energy within 13 years. Later operation in Wuppertal will result in an almost identical demand but less surplus (4,700 kWh). [6]

Fig. 8: View to the south facade with PV wall (front) and vacuum tube collectors (back).
Source: Peter Keil, Düsseldorf

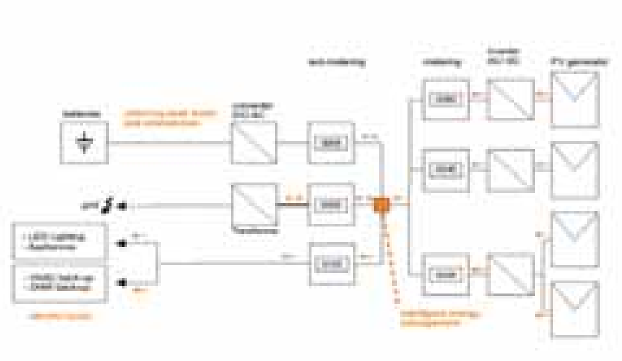

Fig. 9: Layout of the electric system

2. Results from Madrid and Comparison of the Houses

During the competition data concerning the electrical consumption, PV yield and grid supply have been collected. The results are given in fig. 10 for three of the German houses (Rosenheim, Stuttgart, Wuppertal).

The PV yield of Rosenheim is significantly higher compared to Stuttgart and Wuppertal. This is due to the installed PV modules covering all the roof. With regard to the high summer position of the sun this allows for a high generator output. The facade integrated PV modules of Stuttgart and Wuppertal do not contribute too much in June.

It can also be clearly seen from fig. 10 that the PV yield exceeds the consumption by far. Also, by optimizing time syncronization of PV yield and consumption to a maximum the resulting grid supply could be reduced to a minimum. Therefore, the houses and their electrical consumtion show a minimum impact to the public grid.

Fig. 11 depicts key weather data, global radiation and ambient temperature, during the competition time in Madrid.

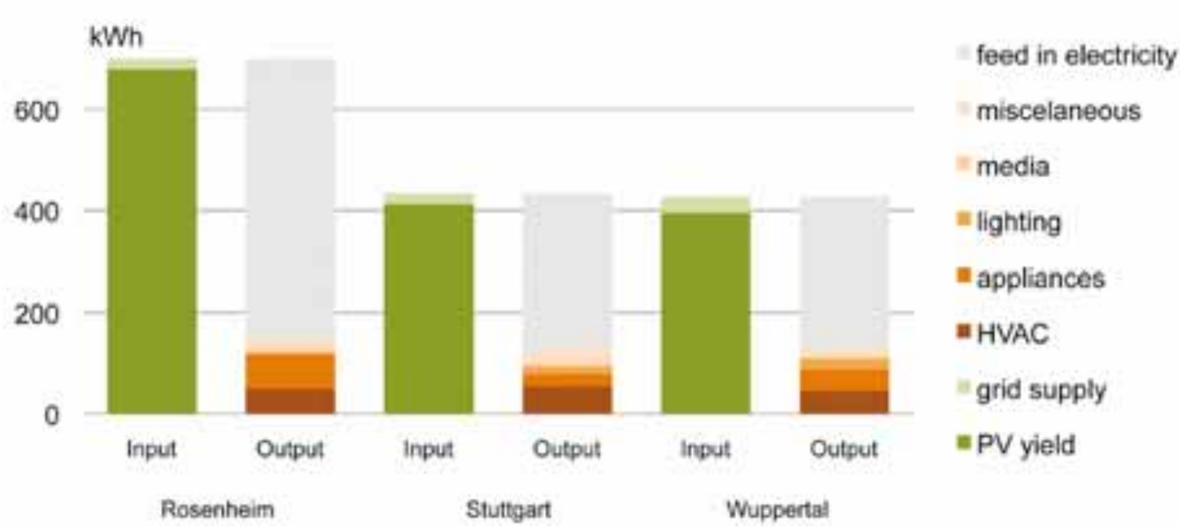

Fig. 10: Comparison of electrical energy balance for three of the German teams (competition time June 2010 Madrid)

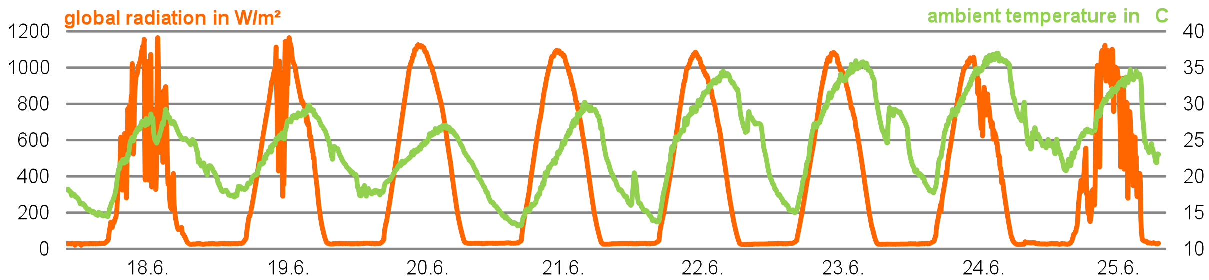

Fig. 11: Global radiation and ambient temperature, competition time in Madrid

3. Conclusion

Concering the final scoring results of the competition, all the four German teams have been very successful with Rosenheim ranking 2nd (810,96 points, Virginia as the winner with 811,83 points), Stuttgart 3rd (807,49 points), Wuppertal 6th (772,72 points) and Berlin 10th (728,85 points). The four German projects show a high quality level with regard to the architectural integration of solar systems being a result of constant work in the area of research and development. The requirements of the competition concerning the energy balance were quite easy to fulfil - high consumption was not a big drawback. As a result, installed high cooling capacity has been a big advantage with regard to the very narrow temperature limits (23-25 °C), the high ambient temperature (36 °C) and the very short adaption time between public house visits and times of measurements (in fact less than half an hour).

In the future, more emphasis should be put on real energy efficiency. Also, adoptive comfort standards should be applied (e.g. DIN EN 15251) to allow for a better use of passive solar options and solutions. A "no-tech" contest should be considered where the comfort and light level of the building is measured with all active systems turned off. Some advice for the next Solar Decathlon Europe has been put in a proclamation draftet, signed and published by all the 17 participating teams in Madrid [7].

4. Acknowledgement

The four German teams have been substantially funded by the German Federal Ministry for Economics and Technology (BMWi) being part of the framework „EnOB (Forschung für Energieoptimiertes Bauen)“.

References

[1] All the projects have been executed by teams of students, assistants and professors. This also applies to the work presented in this paper. To learn about all people involved, please refer to the team-websites listed below.

[2] Solar Decathlon Europe 2010, Rules and Regulations, Draft 5, Universidad Polytécnica de Madrid, http://www.sdeurope.org

[3] Team Berlin living EQUIA (Hochschule für Technik und Wirtschaft Berlin, Beuth Hochschule Berlin, Universität der Künste Berlin), visit http://www.living-equia.com

[4] Team ikaROS Bavaria (Rosenheimer Solar Haus) - Hochschule für angewandte Wissenschaften Rosenheim, visit http://www.solar-decathlon.fh-rosenheim.de

[5] Team HFT Stuttgart (home^{+}), visit http://www.sdeurope.de

[6] Team Wuppertal - Bergische Universität Wuppertal, visit http://www.sdeurope.uni-wuppertal.de

[7] Solar Decathlon Europe Proclamation, published in Madrid on the final award ceremony on June 27th 2010 by all of the 17 participating teams.