Thermal flow simulation for an energy garden building block

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Abstract. Since energy-efficient construction is of great importance, new construction and rehabilitation methods concerning this topic will always be researched. Among these are of course, methods that benefit from solar energy. As part of the BMWi project (Federal Ministry of Economics and Energy) "SWIVT" several options of the energy consumption of residential building blocks will be explored. One of approaches to reduce the energy consumption of the building block and additionally to achieve the energy gain through the solar radiation is an energy garden building block (glass porch). The impact of this energy garden is depicted by means of CFD-simulations (Computational Fluid Dynamics) and will be analyzed in the paper [1]. For this purpose, an energy garden was modeled using an architect drawing and simulated in both winter and summer load cases. For the winter case, the difference in energy consumption between the glass porch and the thermal insulation composite system (ETICS) will be discussed based on the results of the simulation. For the summer, the heat generated by solar radiation in the energy garden can be utilized with the help of a heat pump.

1. Discretization of the solar garden in a 3D model

The building concept of the building block provides for an attractive living environment in which the required energy supply systems can be integrated without restricting comfort and aesthetics. Hence the solar radiation offer is of central importance. The locally available solar radiation offer is to be used both electrically and thermally. The architectural design provides, according to current considerations, basically an outer contour with familiar building geometry. As part of this research, a preliminary study using CFD simulation (Computational Fluid Dynamics) for an energy garden has been carried out. The aim of the investigations was to determine which parameters have a major influence on the design of such an energy garden [2].

1.1. Determination of influencing parameters by means of pre-simulation of an energy garden

Figure 1 shows the energy garden, as it was taken into account in its geometry and its rooftop slope in the simulation. It is planned to build the energy garden directly to a small building, whereby the orientation of the energy garden in a southeasterly direction is being considered.

Semi-transparent PV glass modules are to be arranged in the roof for electrical energy production. In the calculation a 50% PV occupancy was assumed. The energy garden is planned with a depth of 5 meters in its base and a height of 11 meters on the wall of the house.
For the CFD analysis, the energy garden was first divided into numerous small volume elements. All volume elements are to be networked so that as a result of this so-called discretization, a model is created. With this model the room air flows, temperature distributions, etc. that occur in the energy garden can be mapped with sufficient accuracy. Since a three-dimensional volume grid would require a very large number of volume elements (1 to 2 million elements), a two-dimensional model was used to limit the computation times required to analyze the flow and temperature conditions in a cross section depending on daily and seasonal influences.

Figure 2 shows the grid generated for the analysis of operations in the energy garden. It can be seen from the element grid that the grid is more finely divided in the near field of the envelope surface components than in the center of the energy garden, e.g. on the glass facade, the wall and the floor. Despite the simplification, the network has a total of 19127 cells.

The simulation is based on the following boundary conditions:

- Stationary winter case on a sunny day at 13:00 with 6 °C air temperature.
- Soil temperature of 12 °C at a depth of 3 m.
- Indoor building temperature of 21 °C.
- Direct solar radiation of 300 W/m²
- Diffuse solar radiation of 150 W/m²

1.2. Evaluation of the pre-simulation

The results of the simulation are illustrated in figure 3. The temperature stratification are significantly, which leads in the upper areas of the energy garden despite the winter day to a warming of the room air to 27 °C. The temperatures in the interior of the energy garden let the warmed up air rise.

The streaming lines are shown in figure 4. Thus, the air attaches to the heated concrete wall and moves at a speed of about 0.15 m/s upwards. At the glass pane, the rising air cools and moves down again according to the density differences at a speed of about 0.15 m/s. The warm air builds up in the energy garden. Compared to the solar heating of the wall the air temperature remains low due to the broadest transparency of the glass surface of the energy garden. Only in the areas occupied by PV modules the solar radiation is absorbed and it leads there to a warming. Nevertheless, in the simulation, the glass pane remains in a significantly cooler situation than the opaque wall surface of the building.
The heat ingress and thus the warming of the energy garden depend on the weather conditions and the time of day. According to the radiation conditions and the temperatures prevailing inside and outside, the component heating or cooling and the flow processes occurring in the room air of the energy garden change. In order to analyze these, in-stationary calculations were carried out.

As an example, figure 5 shows the heat fluxes of the winter garden enveloping surfaces on two consecutive sunny winter days. In the outside air, a maximum temperature of 6 °C and a minimum temperature of -3 °C were applied in the night hours. The heat fluxes occurring over the envelope surface components are shown in figure 5.

In this case, it must be taken into account in the case of the negative heat flows that the heat enters the energy garden via the envelope surface component. In the case of a positive sign, the heat flows out of the energy garden via the respectively considered component.

Thus, figure 5 illustrates that, as was to be expected, the heat during the day was obtained in the opaque surface of the building wall as well as the floor by absorbing the solar radiation that had entered through the semitransparent glass surfaces. At night, on the other hand, the heat is radiated back to the surroundings and dissipated by convection from the glass surfaces to the outside air.

The heat flows through the semi-transparent PV glass modules on the roof surfaces as well as the glass facade (South) increase towards noon to 34 and 45 W/m² respectively. The reason for this is that the short-wave solar radiation enters the interior directly through the transparent glass areas and is absorbed on the opaque component surfaces (wall and floor) and thus leads to an increase in the partial surface temperatures of the building components. Accordingly, the air flowing past the warm component surfaces heats up. With the warming of the air temperature in the energy garden, however, the heat losses to the outside rise as a result of an increase in the temperature gradients on the glazing and explain the increasing heat flow during the daylight hours. In comparison to the solar energy gains during the sunshine hours, these losses are comparatively low, so that there is still a constant gain of energy in the energy garden. After the setting of the sun, the heat loss in the garden decreases again as the temperature around the glazed surfaces of the energy garden falls and thus the temperature gradient is significantly reduced. Thus, the heat transfer over the transparent surfaces decreases to 11 and 26 W/m².
With regard to the heat fluxes of the wall and floor surfaces, it should be considered that both components are warmed up as a result of the solar radiation passing through the transparent glazing and their absorption during the course of the day. There is a heat entering the interior of the component, i.e. the direction of the building and the earth. The heat absorption decreases only when no further heat is supplied to the components due to the setting of the sun. This decline, however, due to the heated air in the energy garden further leads to an ever more attenuating heat absorption. But as soon as the room air cools more strongly due to the heat loss of the glazing, the heat flow in the component is reversed and the wall as well as the floor return heat to the energy garden, which leads to a stabilization of the air temperature in the energy garden. The maximum heat dissipation of the wall in the night hours is about 39 W/m². At the floor this is only about 29 W/m². The heat, which arises during the tanning, flows to the ground or to the building amount to approx. 33 W/m² for the floor and approx. 13 W/m² for the wall. The larger heat effluents of the wall to the room side explain themselves with a larger solar radiation yield, since the wall surfaces are better acted upon by the flat inclined solar rays than the bottom surfaces, which receive only a fraction of the direct solar radiation due to the angular ratio of the incident radiation and the inclination of the component surface.

For the assessment of the energy garden is essential, however, that the wall is heated because of the daily warming due to absorption of the incident radiation and a constant heat input sets and this only after 22 o'clock its sign changes, so that the bordering on the energy garden wall only during five to six hours as loss area. In addition, the energy supplied by radiation of the wall is supplied to the adjoining living space, so that the energy garden not only limits the loss on the opaque wall, but also allows a solar gain for the opaque component [3].

2. CFD Simulation of the energy garden

2.1. Simulation of a winter case
The Institute of Statics and Design at the University of Darmstadt has designed several scenarios for some building blocks. For these CFD simulations, the energy garden was selected in figure 6. This selection has two important reasons:

- The orientation of the energy garden is in south-west direction
- Existence of a large volume of air under the roof (i.e. more warm air for the heat pump used in summer)

The geometries of the energy garden are shown in figure 6 (right).
Figure 6. The regions to be simulated (left) Geometries of the Energy Garden in [m] (right).

Figure 6 (left) shows the different areas of the simulation grid. In winter, the energy garden acts as a buffer zone, which is warmed up by the solar radiation and thus reduces the heating energy demand of the house.

The CFD simulation should compare the effect of the insulation with the influence of the energy garden. On the southwest side is the energy garden, in which the wall of the ground floor, the first and second floors are not insulated, the wall of the third floor is insulated on the northeast side and not covered with the energy garden. After the simulation, the heat flows through the two wall cases are compared (isolated without energy garden, not isolated with energy garden).

Boundary conditions for the winter case simulation:

- Outside air temperature: -2 to 6 °C
- Soil temperature: 12 °C
- Room temperature: 21 °C
- Physical simulation time: 24 hours

The PV modules on the roof are semi-transparent and reduce continuous solar radiation by 50 percent.

Figure 7 shows the temperature distribution in the garden (winter fall) at 13:00 with a clear sky and an outside air temperature of 6 °C without ventilation. The temperatures in the garden average around 28 °C. The temperatures on the balconies are between 20 and 26 °C, while the temperatures under the roof rising to 31 °C.

Figure 7. Temperature distribution in winter.
Figure 8 shows the heat flows through the outside wall. The energy garden reduces the heat losses on the outside wall up to 20 W/m² during the day and up to 15 W/m² during the night. Thus, the energy garden in this case is much more energy efficient than the insulation.

2.2. Simulation of a summer case

The main function of the energy garden takes place in winter. However, as the energy garden will remain even in summer, the heat generated in the garden should be used effectively. For the determination of the temperatures in the summer a similar simulation was carried out as in the winter case.

Boundary conditions for the summer case simulation:

- Outside air temperature: 18 to 32 °C
- Soil temperature: 12 °C
- Room temperature: 24 °C
- Physical simulation time: 24 hours

Figure 9. Temperature distribution in summer without ventilation (with and without heat pump).
Figure 9 (right) shows the temperature distribution in the garden (summer case) at 18:00 with a clear sky and an outside air temperature of 30 °C without ventilation.

The reached temperatures above 50 °C under the roof are not surprising, because the solar radiation heats up the air volume, which remains closed without ventilation for a longer irradiated period on a summery day. This heat can be effectively and long-term gained by a heat pump.

Figure 9 (left) shows the temperature distribution in the garden after the heat pump with a cooling capacity of 5 kW was used. The used air / water heat pump (LWD 7070A / RX-HMD 2R) can achieve a cooling capacity of approx. 6 kW at a cooling circulating temperature of 7 °C, as shown in figure 10.

![Figure 10. Cooling capacity curves of the heat pump LWD 7070A / RX-HMD 2R [4].](image)

The heat pump is connected to a network of air ducts and must be installed outside the building. The warm air is supplied through the air ducts of the heat pump and thus heats the cooling circuit water. As a result, the air cools down again and is lead away into the garden. The warmed-up water is introduced into a water tank for subsequent use for various purposes. Thus, e.g. hot water to be prepared with low energy. In transitional phases, such as in autumn or spring, the heated water can be used for underfloor heating.

2.3. Simulation of a ventilation process in summer

The high temperatures in the garden under the roof are maintained despite the use of a heat pump, which is why regular ventilation must be carried out.
Figure 11 shows the temperature distribution for a one-minute ventilation of the energy garden. The opposing windows on the roof were opened in the simulation, and an airflow of 2.3 m/s flowed from south-west to north-east direction. The results show that the energy garden can be ventilated within one minute. The average temperatures in the energy garden after ventilation are only up to 2 Kelvin higher than the ambient temperature. Within one minute, the temperatures in the garden have dropped from 46 °C to about 34 °C. The balconies were not ventilated here, because in real life, every resident wants to determine the ventilation strategy himself. Therefore, there is no need to design an automatic ventilation mechanism specifically for the balconies.

References
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