Passive Cooling Strategies in Plus-Energy Houses

Cook MJ[1], Babich F[1,*], Papachristou G[1,*] and Cremers J[2]

[1] School of Civil and Building Engineering, Loughborough University, Leicestershire, UK

[2] Faculty of Architecture and Design, Hochschule für Technik (HFT), Stuttgart, Germany

[*] Equal contribution

Motivation for the work

Cooling homes is important in order to maintain acceptable internal comfort, especially in a warming world. This is set alongside the Energy Performance of Buildings Directive of the European Commission which has set a zero energy goal for all new buildings by the end of 2020. One of the relatively recent housing concepts is the plus-energy house which produces more energy than it consumes. Plus-energy houses are generally ventilated by MVHR (mechanical ventilation and heat recovery) systems. However, concerns have been expressed over the performance of such systems in terms of indoor air quality, thermal comfort and total carbon emissions. Much research has been completed, and case study buildings constructed, which demonstrate the advantages and success of natural ventilation as an alternative to MVHR. This presentation uses one of the winning entries to the Solar Decathlon (Europe) competition and investigates refinements to the performance of two passive cooling strategies used in the building.

The Building

Home+ is a plus-energy house located in Stuttgart, Germany. It was designed and constructed by an interdisciplinary team of architects, interior designers, structural engineers and building physicists at the Stuttgart University of Applied Sciences as an entry for the first edition of the Solar Decathlon Europe competition (Cremers et al, 2010). The final stage of the competition was held in June 2010 in Madrid and home+ won third place. Recently, it was reconstructed in Stuttgart and is used as a permanent research facility.

The house consists of four opaque modules which are positioned a short distance apart. The resulting interspace is glazed with the intention of providing daylight and ventilation to the interior that is enclosed by three of the modules. The fourth module serves as a loggia outside the main entrance. The entire external surface of the building is covered with photovoltaic elements. A main feature of home+ is its “ventilation tower”, which is located between the third and the fourth module (Figure 1).

Figure 1. Exterior view of home+ (after Cremers et al, 2010).

The entrance is located on the southwest corner of the house. The 1m wide corridor leads to the kitchen, while the east side comprises the living room and the dining room which are interconnected. The ventilation tower separates the bedroom from the rest of the house, and the bathroom is located on the northwest corner.

Home+ has a total usable floor area of 56m² and a floor to ceiling height of 2.5m. The lengths of the east/west and north/south façades are 8.9 m and 6.6m respectively. The ventilation tower extends 1.9m above the roof level.

The house has a timber structure, which makes it very lightweight. It has very high standards of thermal insulation and all the windows are triple glazed. Home+ uses a range of innovative passive and active systems in order to provide thermal comfort to the occupants, while keeping the energy consumption low. A description of these systems can be found in Cremers et al (2010).

Despite the advanced design and construction of home+, the tower did not contribute as much cooling as expected. Hence, there was scope to investigate improvements to the passive and cooling and ventilation strategy. This work is presented here.

Simulation Methods

Two options for modifications have been tested using computer simulation. The first series of simulations looked at the contribution of a passive downdraught evaporative cooling (PDEC) tower to the summertime cooling energy consumption in eight Mediterranean locations. Dynamic thermal modelling (DTM) was used to estimate mean and peak CO_2 levels, moisture content, energy consumption and likely water consumption of the system. The post-processing method used in the DTM was based on ventilation flow rates which were obtained from computational fluid dynamics (CFD) simulations. The CFD simulation was used for a single point in time in June at which the cooling tower was likely to be in full operation. The CFD model was also used to predict fresh air distribution, indoor air quality and cooling potential.

The second series of simulations investigated the influence of CO_2-based control algorithms on the ventilation performance. In this case the evaporative cooling tower was not used. Ventilation was achieved by cross ventilation from low-level openings to the stack in summer, and cross ventilation through high-level openings (no stack) in winter. DTM was used to test a combination of one- and two-step opening increments with two different CO_2 set-points. Each combination was tested with and without night cooling.

Results and Conclusions

Simulations predicted that both modifications were capable of delivering good indoor air quality. Results using the PDEC approach showed that the annual energy demand for space cooling could be as much as halved in some locations without jeopardising thermal comfort. However, this does not mean that every plus-energy home in the regions tested must have a ventilation cooling tower. Findings simply tell us that it is likely to be an efficient solution: methods for testing its performance in other buildings and locations will be provided in the presentation.

Simulations of the CO_2-based control strategies resulted in an annual energy surplus of 969kWh for Stuttgart (15% of the energy consumption for the building). It was also found that the integration of night cooling was fundamental to the success of the strategy. All control strategies that did not use night cooling failed to meet the summer thermal comfort criteria set. The design resulting from this series of simulations was also tested for two locations in the UK without further refinement, where it was predicted to use 10% - 16% less energy for space heating.

Cremers J., Fiedler S. and Palla N. 2010, Home+, Solar Decathlon Europe.