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ANALYSES OF PASSIVE COOLING STRATEGIES´ EFFECT ON OVERHEATING IN LOW-ENERGY RESIDENTIAL BUILDINGS IN DANISH CLIMATE

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INTRODUCTION

Increase of outdoors temperature, due to climate changes, results in warmer summers even in cold climate regions. Moreover the use of wider glazing surfaces leads to high amount of incoming solar radiation. As a consequence, the moving toward low energy buildings with the improved airtightness is raising the issue of overheating even in the middle seasons creating not negligible thermal discomfort. The use of mechanical ventilation has increased for guarantee the indoor air quality for the occupants and, with the new rising issue of overheating, it may increase more for compensate the higher indoor temperatures at the expenses of higher energy need.
Orme et al (2003) found solar radiation and ventilation rate the factors that mostly cause overheating in well-insulated buildings. The importance of solar radiation impact on eight passive houses located in Denmark has been reported by Larsen et al (2012). Janson´s (2010) found that an excessive indoor temperature had also considerable electricity consumption and that the desired indoor temperature was 22-23 ˚C.
Through building simulation program, the effect of passive cooling strategies, such as solar shading and natural night-time ventilation, for different boundary conditions were evaluated.
Night-time cooling ventilation can be a very powerful technique, while can also present considerable restrictions as condensation and moisture problems, privacy and/or security problems, etc. The use of this cooling technique and the evaluation of its limitative applicability were investigated

METHODOLOGIES

1-1/2 story single-family house, located in Copenhagen’s climate, was chosen for the calculation model (Kragh et al, 2008). Toward even lower energy building, a high insulated building was considered (U=0.18 W/m^{2}K of opaque and U=0.583 W/m^{2}K of glazed surfaces). Through a computer simulation program, the model was used to calculate the yearly energy demand for the chosen low energy residential building, and in particular to identify the time of the year when cooling is needed. The implementation of heat recovery (HRV) in the mechanical ventilation system, the use of passive cooling strategies (e.g. solar shading and night cooling ventilation), the behavioural action of the occupants on opening the windows, and other factors were considered and implemented in the calculation of the cooling energy demand.

The Energy and Indoor Climate Visualizer (EIC Visualizer, 2012) based on IDA-ICE software was used for running all the simulations. This software allowed identifying the exact moment in which a change like the opening or closing of a window was occurring.
The automatic solar shading system was based on a PI controller activated when the increasing mean air temperature reaches the selected set point of 23°C. Sunshades were used in order to maintain the indoor air temperature by modulating the windows´ incoming solar radiation. A nighttime schedule was implemented for controlling the automated windows opening during the whole night based on two set conditions:

1. Indoor air temperature (t_a) above the selected threshold of 23 °C (Pellegrini et al., 2012);
2. Indoor air temperature (t_a) higher than outdoor temperature (t_{out}).

The nighttime control conditions were both checked at 10 p.m.. If the recorded temperatures were satisfied (t_a<23 °C and t_a>t_{out}) the windows were opened for the entire night, and controlled and modulated according:

- if t_a>23.5 °C, the windows were fully opened;
- if 23.5°C< t_a <22.5 °C, the windows opening was modulated;
- if t_a < 22.5 °C, the windows were fully closed.

Moreover, indoor air quality and thermal comfort conditions were calculated and compared according to EN 15251 (2006) categories. The total energy demand/consumption (heating, cooling, ventilation (incl. fans and heating-coil consumption), domestic hot water and auxiliary) were calculated in terms of primary energy. According to EN 15203 (2006), for the electric consumption of cooling and ventilation systems, and pumps a coefficient of 2.5 has been assumed, while 1.0 was the coefficient chosen for the heating system, AHU's heating coil and domestic hot water. The Ventilative cooling systems (through windows opening or mechanical ventilation system assisted only by a fan) were the main concerns of this study.

RESULTS AND DISCUSSION

The use of night cooling ventilation (NNV) through windows opening resulted to have the lowest energy consumption with 46.3 kWh/m^2 year. However, the best solution was considered being provided by the building model (M_SS_NNV_HRV) with integrated the solar shading system (SS), the NNV and the heat recovery ventilation (HRV). This model M_SS_NNV_HRV resulted the most environmental/energy friendly solutions with 46.9 kWh/m^2 year of energy demand and in good indoor environmental quality (not too high values of air velocity).
The use of the shading resulted more dominant for the high insulated building. In countries like Denmark with low sunshine hours, the high use of solar shading can make the habitants reluctant and looking for alternative cooling systems like electrical stand fans, or fan coil, or other higher energy need cooling devices. For that reasons, passive strategies of nigh-time ventilation for cooling (ventilative cooling strategies) were more analyzed in this study.
Because of some drawbacks, e.g. rainy nights, high outside noise level badly impacting on sleeping quality, security, etc., the support of a cooling active strategy was considered. In terms of ventilative cooling, this means that the mechanical ventilation system assisted by a fan (MNV) was used for bringing the non-treated air from outside to inside. It resulted in a small increase of energy consumption for ventilation (11.5 kWh/m^2 year against of 9.4 kWh/m^2 year for NNV), and in the air change rate higher than 0.5 h^{-1} at the occupancy time but controlled and below 1 h^{-1} (lower than the average 1.8 h^{-1} that occurred with windows opening). Both ventilative cooling models satisfied the raising cooling demand, indoor air quality and thermal comfort. However when looking at the operative temperature profiles, MNV resulted more constant and just below 26 ˚C with temperature of 1.5-2 ˚C higher than NNV, having also the solar shading system ON during all summer season.

When the opening period of the windows was calculated, has been noted that the windows to Nord-Est were opening more often than the opposite ones directed to South-West. This result may look unreasonable even though it could be due to the fact that the used building model was considering one indoor zone. This indicate that further studies, with split indoor space, may return different result where the expected higher warms conditions at the South facade may not be fully satisfied with the only ventilative cooling strategies. The use of automated control of solar shading, when the solar sun radiation is directly impacting on the window surface should be considered. Authors believe that this solution will compensate for the undesired heat gain and will be well accepted by the building users.

CONCLUSIONS

Moving towards zero energy buildings may implement the heating energy save of 69% but it will generate also in cold climate as Denmark the cooling energy demand of 21.4 kWh/m^2 year. Building Simulations showed that the “overheating” issue will occur not only in summer but also during the shoulder seasons more difficult to be controlled. The building simulation model implemented with night cooling ventilation (open windows) and solar shading resulted to be the most environmental/energy friendly solutions (with lower air velocity).

Known that in Denmark building´s users are not well keen to use solar shading, ventilative cooling solutions were mostly focused on: night cooling ventilation introduced by the windows opening or through the mechanical ventilation system supported only by a fan. Even if both solutions nullified the cooling demand, the night increased air change through the mechanical system helped to eliminate security problems, and etc., but resulted in constant indoor temperature just below 26˚C , which will not satisfied the desired 24 ˚C of indoor temperature. Other possibilities to reduce the overcoming overheating issues for low-energy houses in cold climate, with regards of indoor air quality and thermal comfort, building users and behaviour, should be considered for further studies.

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