CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 5

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Ventilative Cooling Potential in Low-Energy Dwellings – The HoTT Case Study

Bouwens, E.P.M., Loomans, M.G.L.C. *, Hensen, J.L.M. , Lichtenberg, J.J.N.

Department of the Built Environment, Eindhoven University of Technology

P.O.Box 513, 5600 MB Eindhoven, The Netherlands

*m.g.l.c.loomans@tue.nl

Abstract

Research indicates that low-energy dwellings are more sensitive to overheating than regular dwellings. In this research the ventilative cooling potential of low-energy dwellings is considered. A low-energy dwelling based on the Active House concept, "House of Tomorrow Today" (HoTT), has been investigated as representative for low-energy dwellings in general. A computational model of the house was created with the software TRNSYS (in combination with CONTAM) and this model has been calibrated with actual (intervention) measurements in the HoTT. The potential of creating or maintaining thermal comfort in the house by applying ventilative cooling has been considered. The simulation results show that ventilative cooling in combination with other design requirements (sun shading and thermal mass) is able to significantly reduce the overheating potential for current typical Dutch summer climate conditions and provide with that a more robust solution for future climate developments with less need for active cooling. Lack of inclusion of these design principles will affect the indoor conditions significantly. As HoTT applies a relative lightweight construction the advantage of thermal mass is less well exploited. However, in an overheating situation, the potential of ventilative cooling in the current HoTT-design can be increased, i.e. higher air change rates can be obtained, by enlarging the currently fixed limited atrium window opening areas. The results confirm that overheating mitigation is an integral design problem.

Keywords – ventilative cooling; measurement; Trnsys; active house; design guideline

1. Introduction

Current building regulations require the design of low-energy dwellings. However, low-energy dwellings appear to be more sensitive to overheating than regular dwellings [1]. Increased insulation and air tightness avoid heat gains in buildings to be dissipated quickly. To some extent this can be anticipated to by introducing the option of ventilative cooling in the design concept. The work in IEA Annex 62 [2] intends to promote the concept of ventilative cooling as it aligns well with the low-energy concept. In this research the potential of cooling with natural ventilation, ventilative cooling, in low-energy dwellings has been investigated. In this case a low-energy dwelling based on the Active House concept, “House of Tomorrow Today” (HoTT), has been investigated as representative for low-energy dwellings in general (Figure 1). The HoTT-project concerns a detached family dwelling [3] located in the south of the Netherlands. The orientation of the house and the location of the windows are designed to capture much daylight, but to prevent an excessive amount of sunlight. This study wants to answer the research question to what extent overheating can be prevented in HoTT and how quickly HoTT can be cooled down through application of the ventilative cooling principle.

Figure 1 – Impression House of Tomorrow Today (HoTT)

2. Method

The in this research applied performance indicator for thermal comfort and overheating is the comfort band for the neutral temperature as function of the reference outdoor temperature for residential buildings from Peeters et al. [4]. They considered the existing approaches, e.g. [5], for thermal comfort in the context of residential buildings. Focusing on residential buildings, they stated that indoor conditions in dwellings are not in line with the requirements for which PMV and PPD indicators have been derived [6]. These indicators focus on steady state conditions in office buildings. Domestic areas cannot be considered as steady state: both the activity level and the clothing value can vary within small periods of time. Internal gains and occupancy are also likely to fluctuate as well. These fluctuations affect the indoor temperature and the required air flow rates on short notice. The indoor comfort temperature is stated to be the most important indoor environmental performance indicator of a residential building, so the effects of design changes and control actions to the HoTT have been compared to this indicator. Peeters et al. specified three different thermal zones in residential buildings: bathroom, bedroom and other rooms. The third category defined by Peeters et al. are the kitchen, living room and study room, which have physical activity levels comparable to those in offices. More adaptive options, however, are available (changing activity, going to another room, drinking cold or warm drinks, etc.). The neutral temperature therefore can have a closer relation with the outdoor climate than what generally is accepted for offices (see Figure 2).

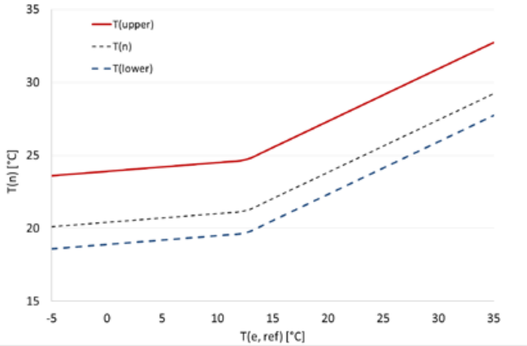

Figure 2 – Comfort band living room, kitchen and office as a function of the ambient temperature [4].

Information on the thermal behavior of HoTT has been obtained by using the building energy simulation tool TRNSYS [7]. This tool offers the possibility to implement overheating prevention strategies in the model and allows the inclusion of air flows in the model by the TRNFlow tool or, as applied in this case, CONTAM [8].

In order to simulate reliable results with the TRNSYS model, the preliminary model has been calibrated. Three sets of measurements have been performed in the actual house to obtain information on the actual physical behavior of the house. The goal of the calibration process has been to improve the accuracy and reliability of the simulation results. This has been arrived at by fitting the model in such a way that the simulation results corresponded best to the measured results. Subsequently, the calibrated model has been applied in elaborated cases in order to investigate the prevention of overheating and the ability of ventilative cooling.

In the calibration process first measurements of resulting temperatures have been obtained when the dwelling was exposed to free floating conditions (no mechanical heating nor cooling and no ventilation). Secondly, air temperature curves have been obtained as a result of the application of the hybrid ventilation system present in the dwelling. The automatic, CO_2 controlled, system was overruled and specific air flow rates were preset. Applying the same ventilation conditions in the model in otherwise free floating conditions, measured temperature conditions again were used to calibrate the model further.

As a last step in the calibration process air temperatures have been measured as a result of opening of windows in the dwelling, imposing ventilative cooling. Similar window heights and surfaces have been applied in the model in order to simulate temperatures and air flows as measured. Figure 3 presents a visualization of the model applied and a sketch of the (bulk) three-dimensional air flow path as was applied in the measurements and in the simulations.

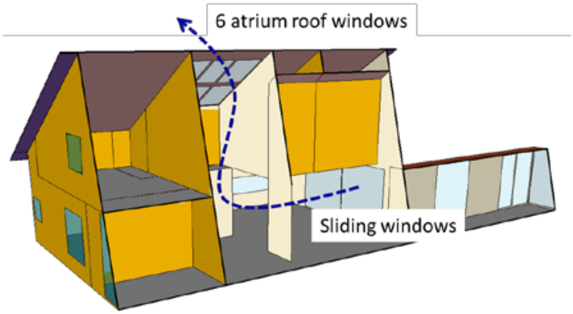

Figure 3 – Modelled dwelling with three-dimensional air flow path as applied.

Measurements were performed with both upper and lower atrium roof windows (three per row), as well as measurements with all six atrium windows opened. A sliding window at ground level in the living room was opened in all of these cases. The measurement with six opened windows was repeated with a different ambient temperature and thus a different temperature difference (ΔT). Each time the windows were opened for 10 minutes. During the measurements, the wind speed was relatively low 1-2 m/s [9]. Wind speed influences the air flow, but the direction of the wind determines its effect (either positive or negative). As wind speed and direction can vary within small time intervals, in order to fit the model to the measurements, only air flow due to thermal buoyancy initially has been considered in the model. Figure 4 presents the measured difference in temperature between indoor and outdoor for the living room and the atrium for the entire measurement period. The absolute ambient temperature is included as well. The blue areas indicate the period when atrium windows were opened.

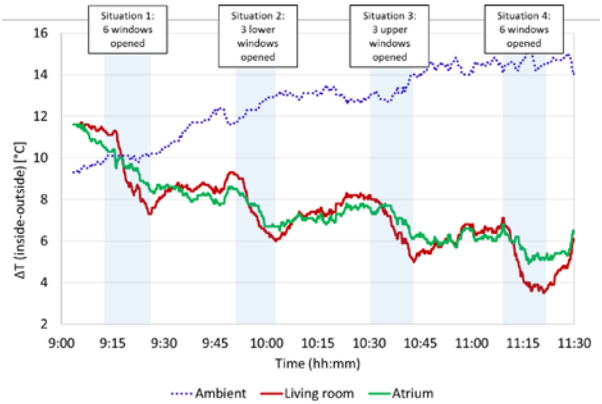

Figure 4 – Temperature difference curves between inside and outside in living room and atrium due to opened windows. Four situations describe different combinations of opened windows.

The measured indoor air temperatures of the living room and the atrium have been averaged to compare to the mean temperature of the zone as obtained from the simulation model. Figure 5 shows temperature differences between inside and outside for a period of 10 minutes for measurement situation 1. In the graph the simulated temperature development and air change rates per hour (ACH) caused by the natural convection are included as well.

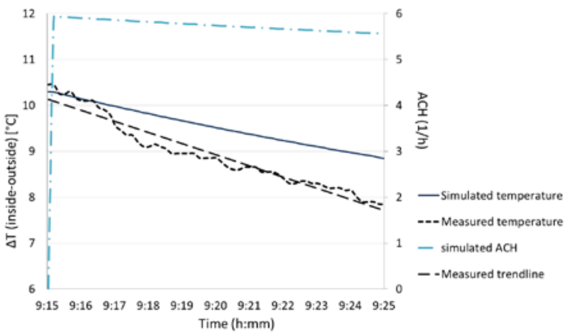

Figure 5 – Measured temperature difference, simulated temperature difference and ACH, six opened windows (situation 1)

Figure 5 presents the results for situation 1, where six atrium windows were opened. The measured results seem to indicate that in reality the house cools down more rapidly than according to the model. However, this can be explained by the fact that local indoor temperatures near the air flow path have been measured (Figure 3), instead of considering the average temperature of the entire zone (as the model does).

The dot-dashed blue line in Figure 5 shows the simulated air change rate per hour as a function of time. As soon as the windows are opened an air flow occurs. As the temperature difference between inside and outside decreases during the measurement period due to the ventilative cooling, the resulting air change rate decreases. From the measurements an indication of the air change rate has been obtained by applying the tracer gas (CO_2 concentration) decay method [10]. From the analysis the air change rate was estimated at 4.8 h^{-1} which is in relative good agreement with the air change rate as simulated for the investigated period (5-6 h^{-1}).

Based on the outcomes, the developed and calibrated simulation model is assumed fit for the assessment of the potential of the HoTT to prevent overheating and to assess the time required to cool down the HoTT with ventilative cooling to a thermally comfortable environment in case of an overheating situation. The first assessment is performed for a warm summer period (Dutch climate). The second assessment assumes a starting condition for overheating at a given temperature difference between indoor and outdoor. The results and discussion of the assessment will be presented in the next paragraph.

3. Results and discussion

Figure 6 presents an overview of indoor temperature profiles as simulated for a summer period. Besides the ambient (outdoor) temperature and the comfort band according to Peeters et al. [4] for these conditions, several temperature profiles are shown which each indicate the outcome for a specific control setting and/or design change. ‘no measures’ assumes a situation where no actions are taken to reduce the overheating potential. ‘VC’ indicates profiles that assume the application of ventilative cooling, either controlled on the ambient temperature only (‘Tamb<20C’) or with the indoor condition included (‘Tin>22C’). The application of external shading assumes that 70% of the window area is shaded. An increased thermal mass assumes that the inner insulation layer is replaced by concrete (0.2m). In combination with an increased thermal mass also night cooling is applied. Figure 6 shows the effect of these different strategies on the indoor temperature. Referring to the comfort band, only one of the solutions as investigated currently is able to completely avoid overheating for the investigated summer period. Too cold conditions as shown can be avoided and are regarded less problematic. Maximum air change rates (not shown in the Figure) during ventilative cooling situations are in the order of 4-5 h^{-1}.

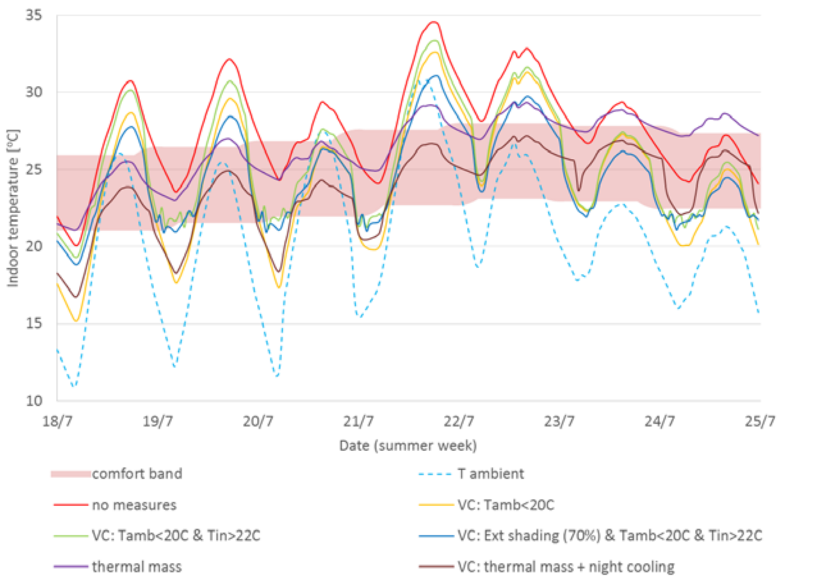

Figure 6. Simulated indoor temperatures for a summer week for different control and design strategies (VC: strategy with Ventilative Cooling included).

Figure 6 indicates that ventilative cooling positively affects the indoor temperature conditions. Limiting the ventilative cooling potential by the indoor temperature set point does not use the current thermal mass potential present in the dwelling. As a result the overheating conditions remain worse, certainly in case of relatively cold nights. Shading supports the overheating mitigation in the same order of magnitude as ventilative cooling does in case of relative cold nights. Increasing the thermal mass in the HoTT damps the maximum overheating on warm days but arrives at higher night temperatures. A combination with night cooling allows an average temperature reduction, day and night, of more than 2°C. A combination with sun shading will allow for conditions which stay well within the comfort band for the investigated warm week.

The HoTT currently does not suffer from overheating as an active cooling system (heat pump) is installed and in use during the summer period. The results show that the proposed design and control solutions can reduce the required active cooling periods and related energy use for the investigated week. With that it also allows for a more robust design solution if future climate conditions are considered.

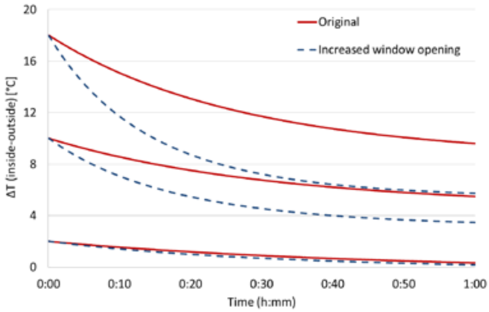

Figure 7 – Cooling effect due to ventilation cooling for current state and with increased window opening area (atrium roof windows).

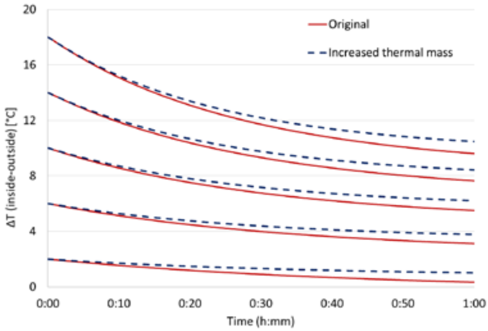

Figure 8 – Cooling effect due to ventilative for current state and with increased thermal mass

Figures 7 and 8 present the cooling effect in HoTT due to ventilative cooling in case of an overheating situation. The figures present the indoor temperature drop when windows are opened for one hour. This is expressed in a temperature difference between indoor and outdoor, assuming a steady-state outdoor temperature for the investigated period. These graphs provide information on how quickly (time constant) an unwanted thermal condition can be corrected. In Figure 7 an increased stack effect is obtained as a result of an increased atrium roof window opening (0.5 m^2 per window instead of the fixed opening area of 0.1 m^2 as present in the current design). In the current state, ventilative cooling due to opened windows at an initial temperature difference of 10°C (e.g., inside 25°C and outside 15°C), results into a reduced temperature difference of ±5.5°C within one hour (hence, the indoor temperature is reduced to 20.5°C). The increased stack effect results into a reduction of the temperature difference to ±3.5°C, which means that the cooling effect is increased (hence, the indoor temperature is reduced to 18.5°C within one hour). In Figure 8, a similar comparison is shown but in this case the thermal mass (0.2 m concrete instead of a steel construction) has been changed. It can be seen that increasing the thermal mass of the house results in a reduced cooling effect, in case of an overheating situation, due to ventilative cooling as compared to the current design. The indoor temperature reduction within one hour is smaller than for the current design. This effect however is much smaller for the investigated time interval as compared to the increased opening area.

The results confirm that for the prevention of overheating lightweight buildings are not advised. Buildings with a high thermal mass have a lower risk of overheating. However, for the HoTT case a clear improvement can be found to mitigate an overheating situation and to more effectively use the present thermal capacity if the currently available option in the design (i.e. increasing the opening area) for ventilative cooling is exploited better.

4. Conclusions

In case of no application of active cooling, the HoTT is susceptible to overheating (Dutch climate). This outcome confirms earlier (simulated) results for low energy dwellings. Use of design and control measures such as ventilative cooling, shading and the addition of thermal mass are able to reduce the overheating potential. Ventilative cooling in this context is one of the measures but not sufficient by itself. Shading is an important minimum design and control requirement. Precooling through ventilative cooling (night cooling) to conditions below the comfort band utilizes the cooling potential better, certainly when combined with additional thermal mass. Nevertheless, in case of warm spells where night temperatures remain relatively high the ventilative cooling potential should be increased. The results show that increasing the opening area in this case is a simple means to arrive at that.

Design of low-energy dwellings requests for a careful consideration of the use of overheating mitigating strategies. The results indicate that this is an integral design problem. Other performance indicators for effective use of the strategies are included in this design problem as well (e.g. safety in use and feeling of safety [11]).

Acknowledgement

The authors would like to thank Vojtech Zavrel for his support in developing the coupled model.

References

[1] M. Hamdy and J.L.M. Hensen, Assessment of overheating risk in dwellings. Paper ID367 in: M.G.L.C.Loomans and M. te Kulve, eds. Proceedings Healthy Buildings Europe 2015, Eindhoven, The Netherlands, pp.9, 18-20 May 2015.
[2] IEA. 2015. IEA Annex 62 – Ventilative Cooling (http://venticool.eu/annex-62-home/).

International Energy Agency.
[3] J.J.N. Lichtenberg, J.J.P. Mak and H. den Dekker. House of Tomorrow Today, Sustainability Analysis. Paper ID479 in: M.G.L.C.Loomans and M. te Kulve, eds. Proceedings Healthy Buildings Europe 2015, Eindhoven, The Netherlands, pp.8, 18-20 May 2015..
[4] L. Peeters, R. de Dear, J. Hensen and W. D'haeseleer. Thermal comfort in residential buildings: comfort values and scales for buildings energy simulation. Applied Energy 86 (2009) 772-780.
[5] A.C. van der Linden, A.C. Boerstra, A.K. Raue, S.R. Kurvers and R.J. de Dear. Adaptive temperature limits: A new guideline in The Netherlands. Energy and Buildings 38 (2006) 8-17.
[6] P.O. Fanger. Thermal comfort. Danish Technical Press, Kopenhagen (1970).
[7] Duffy, M.J. TRNSYS 17 Homepage (2015) http://sel.me.wisc.edu/trnsys (last accessed 2015/11/26)
[8] NIST. NIST Multizone Modeling Website (2015) http://www.bfrl.nist.gov/IAQanalysis (last accessed 2015/11/26)
[9] KNMI. Royal Dutch Meteorological Institute (2015) http://projects.knmi.nl/klimatologie/uurgegevens/selectie.cgi. (last accessed 2015/11/26)
[10] M.W. Liddament. A guide to energy efficient ventilation. International Energy Agency AIVC (1996).
[11] M. Loomans, A. Huovila A., P.H. Lefebvre, J. Porkka, P. Huovila, J. Desmyter and A. Vaturi. 2011. Key Performance Indicators For The Indoor Environment. In: Proceedings World Sustainable Building Conference SB11. Helsinki. Theme 4, pp.1666-1675.