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Control Strategies for Ventilative Cooling of Overheated Houses

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Abstract

Buildings constructed before 1979 in Denmark are responsible for 75% of the total energy consumption of the sector. However, many post-occupancy comfort studies of energy renovated dwellings have documented elevated temperatures not only during the summer period but also during the transition months. Ventilative cooling can be an energy-efficient solution to avoid overheating in energy renovated residences.

The aim of the research is to investigate the ability of a representative manual window use and different automated window control strategies in order to eliminate overheating under different opening positions, wind conditions and discharge coefficients. The study will also include examination of the ability of mechanical ventilation and shading systems regarding the overheating occurrence. The objectives are fulfilled through the simulation and analysis of a real representative single-family house from the 1970s. The case study is renovated deeply and high-efficient (nZEB) creating two different scenarios.

Mechanical ventilation system and manual control of the openings for both renovation scenarios cannot sufficiently eliminate the overheating risk indoors. The discharge coefficient of the windows, the presence of the wind and the opening position of the windows are critical parameters of the effectiveness of the ventilative cooling strategies. The fully all-day automated control strategy presents the best performance among the three strategies of the automated control (parallel use, automated during the occupied period and fully automated). In most of the cases of the parametric analysis the high-efficient renovation scenario presents lower values of overheating risk compared to the deep renovation scenario.

Residential building; renovation; passive measure; building automation

1. Introduction

The building sector is responsible for more than 30% of the energy use [1] and carbon emissions in the European Union [2]. In Denmark the building stock accounts for about 40% of the total final energy use [3]. Buildings constructed before the 1980s are responsible for 75% of the total energy use of the sector [4]. During the 1960s and 1970s, approximately 440,000 (more than the one third in total) single family dwellings were built in Denmark [5]. The majority of them are identical in terms of size, construction systems and materials. These houses were erected without or with the first limited energy regulations. In many cases these buildings have not yet undergone deep or high-efficient energy renovations [6]. In 2012 a broad majority in the Danish parliament agreed on the transition to fossil independency until 2050, by increasing the ambitions regarding energy savings in general [7]. The energy-efficient Danish regulations (BR10 and BR2015/2020) brought important changes in the design process mainly concentrated on an increase of the airtightness and insulation levels of the building [8]. However, in many post-occupancy comfort studies of new or energy renovated dwellings elevated temperatures have been documented not only during the summer period but also during the transition months [9, 10]. As cooling becomes a need not only in the summer period, but also during the transition months, the possibilities of utilizing the free cooling potential of low temperature outdoor air increases considerably. Orme et al. [11] documented that the most important factors causing overheating and discomfort conditions in well insulated houses are the solar radiation and the limited ventilation rates.

Ventilation is already present in most residential buildings through mechanical and/or natural systems and can both remove excess heat gains as well as increase air velocities and thereby widen the thermal comfort range [12]. For home owners cooling is an unknown challenge that they have not experienced before. They do not know how to efficiently reduce the overheating problem indoors and their behavior might instead actually increase it.

The aim of the research is to highlight the problem of overheating in energy renovated single-family houses in Denmark and to investigate the ability of a representative "typical" manual window use and different automated window control strategies in order to eliminate risk under different opening positions (percentages), wind conditions and window discharge coefficients (parametric analysis). The study will also include examination of the ability of mechanical ventilation and shading systems regarding the overheating occurrence. The objectives are fulfilled through the investigation of the comfort conditions of a representative dwelling from the 1970s. The case study is retrofitted deeply and high-efficient (nearly zero energy building-nZEB) creating two different renovation scenarios.

2. Methodology

2.1 Case Study

The case study is a representative one-story single-family house (116.2m2, net floor area) from the 1970s (1973-1978) as extracted from "Typology Approach for Building Stock Energy Assessment" project. The case study is reference by definition, as far as the geometry, size, energy performance, materials, window area and structure of the Danish residences of this period. The case study is a typical heavy-weight construction [13-Fig. 1]. Table 1 presents the thermal characteristics of the dwelling.

The case study is renovated deeply and high-efficient (nZEB) creating two different scenarios (Table 1). In the first step the dwelling is renovated deeply, according to the energy regulations for existing buildings [8]. In the second step the case study is renovated to reach very efficient energy goals (BR2020). Three typical roof windows with south orientation have been used as part of the renovation process. The openings cover the 10%/35%/10%/0% of the external walls (north/south/east/west).

Fig. 1 Case study

Table 1. Thermal characteristics of the case study for different renovation phases

Renovation	U_{wall} (W/m²K)	U_{roof} (W/m²K)	U_{floor} (W/m²K)	U_{window}, g (W/m²K),-	n_{50} (ach/h)
Base case	0.45	0.45	0.35	2.7, 0.76	5.0
Deep	0.20	0.15	0.12	1.65, 0.7	1.6
nZEB	0.10	0.15	0.12	1.2, 0.6	0.8

The analyses were conducted with the use of highly sophisticated building performance simulation tool DesignBuilder version 4.2. The renovation cases were simulated as free floating buildings (transition and summer season), without any mechanical cooling systems. The weather file used in the simulations was well documented, free accessible Energy Plus file (.epw) with hourly data (Fig. 2). The occupancy and internal gain profiles [13] reflect a typical 5-member working family (Table 2).

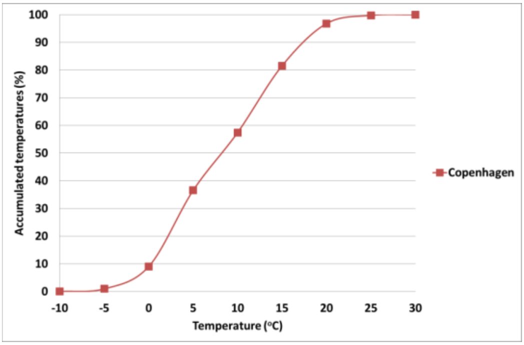

Fig. 2 Accumulated temperature (°C), weather file of Copenhagen, Denmark

Table 2. Occupancy profile

	Monday-Thursday	Friday	Weekend
Occupied	00:00-08:00/ 16:00-24:00	00:00-08:00/ 14:00-24:00	fully
Non-occupied	08:00-16:00	08:00-14:00	-

The overheating occurrence is assessed by the method "percentage outside of the range" of EN 15251:2007 standard [12]. The index measures the percentage of the occupied hours with operative temperatures higher than the upper and lower bound of the adaptive comfort temperature. In our cases for renovated residences, Category II is used. The method is used for the assessment of overheating in "free-running" buildings (no mechanical cooling) and especially residential houses where the options (e.g. access to operable windows) and possibilities of thermal adaptation of the occupants are plenty [12]. The overheating incidents were observed from middle of April to middle of October. No undercooling incidents were observed for the examined period.

2.2 Control Strategies and Parametric Analysis

This research has examined five different ventilative control strategies. The first examined strategy is through the mechanical ventilation system. The air change rate is set to 0.5 ach during all day, covering the minimum indoor air quality requirements (no heat recovery). When the outdoor temperature is colder than the indoor mechanical ventilation offers refreshing air, which decreases the overheating problem indoors. Occupants of dwellings do not use both mechanical ventilation systems and openings as a result of the strict suggestions (oriented to the heating period) of the installers.

Several behavioral models have been developed in the last years aiming to predict occupant-controlled window opening in naturally ventilated or conditioned buildings [14]. These models have been created mainly from data of office buildings and their use is extended to domestic environments. The models created for residential buildings are limited and case study or climate related. Residents of single-family buildings used to open the windows, mainly for indoor air quality reasons or as a result of a “typical” practice, in specific times during the day (morning, after work-cooking time, before sleep). This daily pattern is considered in this paper as “typical” representative manual use (Table 3). The manual opening is applied to all the windows of the case study, independently of the outdoor environmental conditions during the examined period.

Table 3. Typical manual use of the windows

	Opening hours
Morning	07:00-08:00
Afternoon	16:00-18:00
Night	23:00-24:00

For the first two control strategies, overheating was calculated also with the application of different shading systems (drapery, internal/mid-pane/external blinds with high reflectivity) for intercomparison reasons [13]. The shading systems were applied only during the non-occupied period (Table 2) for visibility reasons.

Finally, the last three examined control strategies are related with automated control of the openings:

- Automated control during the non-occupied hours and at night and manual control (Table 3),
- Fully automated (occupied hours),
- Fully automated (all-day).

The automated control for ventilative cooling is based mainly on indoor temperature setpoints and outdoor temperatures. The windows open when the outdoor temperature is lower than the indoor (always over 12.5^{o}C) and the indoor temperature over a benchmark.

Ventilative cooling is vulnerable to constraints and limitations when applied in real cases (e.g. security, outdoor weather conditions, noise, children or animal safety, insects and others). It is important that the control strategies are also examined under different ventilation parameters which affect the performance and effectiveness on the dwelling. This analysis covers mainly three parameters: the discharge coefficient settings, the wind effect and the opening of the windows (Table 4). The indoor natural ventilation temperature set point was set to 22^{o}C to avoid undercooling incidents. This value is the result of desk sensitivity analysis (not presented in this paper) and suggested for the Danish building stock. No undercooling risk is observed for any of the control strategies, parametric analysis and renovation scenarios. The parametric analysis has been conducted for both renovation scenarios.

Table 4. Different values of the analysis

Discharge coefficient (C_d)	0.45/0.65
Wind effect	wind/no wind
Window opening (%)	10/50

3. Results

The comfort assessments, without the use of any shading systems and ventilative cooling through mechanical ventilation systems, show extreme values of overheating (33.4% and 35.8% respectively-Fig. 3). Similar results are presented also for manual control of openings (23.6% and 25.6% respectively-Fig. 4).

The use of different shading systems significantly decreases the overheating occurrences for both control strategies and renovation scenarios (Figs. 3 and 4). For the most effective shading measure (high reflectivity external blinds) the decrease of the overheating risk for the two renovation scenarios is 73% and 70% respectively (mechanical ventilation) and 75% and 77% respectively (manual control). For manual control of the windows and the use of the most effective shading system the overheating risk is approaching the acceptable benchmark of the regulations (EN 15251:2007). Always for these strategies the more efficient scenario presents higher overheating risk.

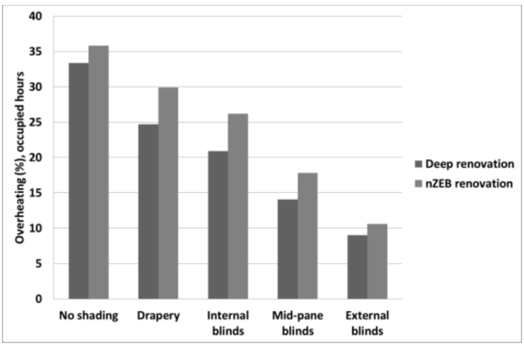

Fig. 3 Overheating assessment (%) without or different shading systems and ventilative cooling through mechanical systems (two renovation scenarios)

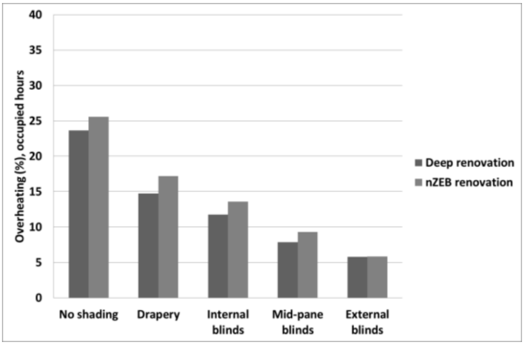

Fig. 4 Overheating assessment (%) without or different shading systems and manual control of the windows (wind effect, discharge coefficient: 0.65 and window opening: 10%, two renovation scenarios)

Manual control for both renovation scenarios and all the examined parameters cannot sufficiently eliminate the overheating risk (over the benchmarks). The increase of the discharge coefficient of the windows, the presence of the wind effect and the increase of the window opening significantly decrease the overheating incidents for both scenarios and all the examined control strategies (manual, mixed and automated). The lowest values are 8.7% and 7.8% for deep and nZEB renovation scenarios respectively. The highest values are 35.5% and 37.2% respectively for low discharge coefficients, low window opening and without wind (urban conditions). In general, the highly open window (50%) is more effective in high discharge coefficients. Window opening percentage seems to be the most crucial parameter for the ventilative cooling effectiveness indoors. In general the increase of the window opening from 10% to 50% result a decrease of the overheating 81.3% on average (79.2% for deep renovation and 83.4% for high-efficient renovation). In addition, for high values of window opening (50%) the nZEB renovation scenario presents lower risk compared to the deep renovation scenario.

Table 5 presents comfort assessments for different mixed or automated ventilative cooling control strategies, wind conditions, window opening percentages and discharge coefficients for different renovation scenarios. The mixed control strategy (manual and automated) is the worst control strategy among the three. For two cases (deep renovation) and for one case (nZEB renovation) of the parametric analysis, the overheating occurrence is over the benchmark of the regulations (5%, EN 15251:2007). The all-day automated control presents the lowest values of overheating occurrence. All the results of the parametric analysis present overheating risk under 5%. For three cases the overheating risk is minimal (zero).

Table 5. Overheating (%) for different mixed and automated control strategies and parameters (two renovation scenarios)

wind effect-C_d-opening	Automated (non-occupied, night) and manual control	Automated control (occupied hours)	Automated control (all-day)
Deep renovation			
wind-0.65-10%	2.4	1.5	0.8
wind-0.65-50%	0.5	0.1	0.0
wind-0.45-10%	3.4	2.7	1.5
wind-0.45-50%	0.6	0.3	0.1
no wind-0.65-10%	6.5	4.7	2.8
no wind-0.65-50%	1.4	0.8	0.4
no wind-0.45-10%	10.1	7.9	5.0
no wind-0.45-50%	1.8	1.0	0.6
nZEB renovation			
wind-0.65-10%	1.4	0.9	0.3
wind-0.65-50%	0.2	0.1	0.0
wind-0.45-10%	2.5	1.6	0.7
wind-0.45-50%	0.3	0.1	0.0
no wind-0.65-10%	4.6	3.3	1.8
no wind-0.65-50%	0.8	0.3	0.2
no wind-0.45-10%	8.1	5.9	3.3
no wind-0.45-50%	1.2	0.5	0.2

On average the effectiveness of the automated control strategies is approximately 95% (compared with mechanical ventilation systems) and almost 90% (compared with manual control of the windows) in overheating terms. The comparison of the results between the manual control and the mixed control highlights the importance of the night ventilative cooling to the design without overheating problems, especially for temperate climates. The forced manual control, in many cases, worsens the comfort conditions indoors because the user allows hot air (e.g. during afternoon) to enter the space (air quality reasons). The mixed control strategy may not be sufficient to compensate overheating issues in residences, which are subjected to climate change effects, even in Denmark in the next decades.

The differences on the results between the most effective automated control strategies are low. For Denmark ventilative cooling may be an effective solution also during the non-occupied hours in the morning. On the other hand, the fully automated all-day control strategy raises serious concern as far as the security of the dwelling because the windows open when the occupant is not at home. Special concern as far as the configuration of these openings has to be taken into account. Contemporary security systems or old fashion metal bars might solve the security issues in case studies where the effectiveness of the control strategy is more profound.

For all the cases of the parametric analysis of the automated control strategies the nZEB renovation scenario presents lower values of overheating occurrence compared to the deep renovation scenario. Ventilative cooling measures controlled by automated systems are more effective to more efficient houses.

4. Conclusions

Mechanical ventilation system and manual control of the openings for both renovation scenarios cannot sufficiently eliminate the overheating risk indoors. For manual control of the windows and the use of the most effective shading system the overheating risk is approaching the acceptable benchmark of the regulations. The automated control of the window openings significantly eliminates the overheating problem indoors for both renovation scenarios in all of the cases. The all-day automated control presents the lowest values of overheating occurrence. The discharge coefficient of the windows, the presence of the wind and the opening position of the windows are critical parameters of the effectiveness of the ventilative cooling strategies. Ventilative cooling controlled by automated systems are more effective to more efficient houses.

Acknowledgment

The authors are presently contributing to the ongoing work with investigating and maturing ventilative cooling as an energy-efficient solution to avoid overheating of buildings, within the IEA EBC Annex 62: Ventilative Cooling.

References

[1] EU Directive 31. Energy performance of buildings. J. of the European Union (2010) 13-35.
[2] Danish Building Research Institute Denmark and Ecofys. Principles for nearly zero energy buildings. Paving the way for effective implementation of policy requirements. Buildings Performance Institute Europe (2011) 1-124.
[3] N. Meyer, B. Mathiesen and F. Hvelplud. Barriers and potential solutions for energy renovation of buildings in Denmark. J. Sustainable Energy Planning and Management 1 (2014) 59-66.
[4] Regeringen. Strategi for reduktion af energiforbruget i bygninger (in Danish). Erhvervs og Byggestyrelsen (2009) 1-60.
[5] A. Mortensen, P. Heiselberg and M.A. Knudstrup. Energy renovation of Danish single-family houses economy barrier, motivation and limit. DCE Technical Reports 190, Aalborg University (2015) 1-51.
[6] K.B. Wittchen. Potentielle energibesparelser i det eksisterende Byggeri. Danish Building Research Institute Denmark, Statens Byggeforskningsinstitut (2009) 1-38.
[7] Accelerating Green Energy Towards 2020. Danish Ministry of Climate, Energy and Building (2012) 1-12.
[8] Danish Building Regulation 10 (in English). The Danish Ministry of Economic and Business Affairs Danish Enterprise and Construction Authority (2010) 1-220.
[9] P. Foldbjerg, E.K. Hansen, L. Feifer and K. Duer. Measurements of indoor environmental quality and energy performance of 6 European zero carbon houses-a case study from the first house. Int. Conf. on Indoor Air, Austin, 8 June 2010.
[10] T.S. Larsen. The Comfort Houses: Measurements and analysis of the indoor environment and energy consumption In 8 Passive Houses 2008-2011. DCE Technical Reports 145, Aalborg University (2012) 1-99.
[11] M. Orme, J. Palmer and S. Irving. Control of overheating in well-insulated housing. Int. Conf. on Building sustainability: values and profit, Edinburgh, 24-26 September 2003. CIBSE.
[12] EN 15251. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. J. of the European Union (2007) 1-52.
[13] T. Psomas, P. Heiselberg, K. Duer and E. Bjørn. Analysis and comparison of overheating indices in energy renovated houses. 14 Int. Conf. on Building Performance Simulation Association, Hyderabad, India, 7-9 December 2015.
[14] A. Mavrogianni, M. Davies, J. Taylor, Z. Chalabi, P. Biddulph, E. Oikonomou, P. Das and B. Jones. The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. J. Building and Environment 78 (2014) 183-198.