Final report

1.1 Project details

Project title	Ventilative Cooling in Energy Renovated Residences
Project identification (program abbrev. and file)	64013-0544
Name of the programme which has funded the project	EUDP, Energy Efficiency
Project managing company/institution (name and address)	Aalborg University, Department of Civil Engineering Thomas Manns Vej 23, 9220 Aalborg Ø
Project partners	VELUX A/S, Ådalsvej 99, 2970 Hørsholm (CVR 30003519) DOVISTA A/S, Vesterled 6, port 30, 6950 Ringkøbing (CVR 21147583) Visility, Universitetsparken 7, 4000 Roskilde (CVR 30827503)
CVR (central business register)	29102384 (AAU)
Date for submission	March 1, 2018

1.2 Short description of project objective and results

The objectives of the project are both to address the design challenges related to reduction of the cooling need and the risk of overheating in energy renovated residences under different climatic conditions through the development of design guidelines as well as to develop attractive ventilative cooling solutions for this building type.

Developed design guidelines for ventilative cooling has been implemented in the Ventilative Cooling Design Guide published by IEA EBC. A special version in Danish focusing on the specific conditions in Denmark is under development.

The project has also developed a new automated window opening control system that significantly diminish the indoor thermal discomfort by overheating. The low energy use of the developed window system and deactivation of the mechanical ventilation system during summer results in a total energy savings of more than 95%

Projektets formål er både at adressere projekteringsudfordringerne relateret til reduktion af kølebehov og risiko for overophedning i energirenoverede boliger under forskellige klimatiske forhold gennem udarbejdelse af guidelines for projektering samt gennem udvikling af attraktive løsninger til passiv køling af boliger med udeluft.

Guidelines for projektering er udviklet i projektet og implementeret i en international design guide udgivet af IEA EBC. En dansk udgave med specifik fokus på danske klima og bygningsforhold er under udarbejdelse.

Projektet har også udviklet en ny strategi for styring af vinduer og solafskærmning, der er i stand til at reducere risikoen for overophedning betydeligt og samtidigt sikre en tilfredsstillende luftkvalitet i sommerperioden selv om den mekaniske ventilation slukkes. Dette resulterer i en reduktion af energiforbruget til ventilation og køling i boliger i sommerperioden på mere end 95%.

1.3 Executive summary

In many post-occupancy studies of energy renovated residential buildings elevated temperature levels is a perceived problem by the occupants and in investigations of the indoor environment carried out in renovated single-family houses temperature levels above 26-27 C are very often found and documented.

The goal of the project was to avoid an increased use of mechanical cooling in residences by offering an effective passive cooling solution based on utilization of the free cooling potential of outdoor air. The goal of the project is also to develop new integrated control strategies for passive cooling measures in residences and especially focus on combined operation of solar shading, thermal mass activation and ventilative cooling.

The project dealt with the goals and objectives through the following activities:

- Mapping of typical existing ventilation systems and technologies in residences.
- Analysis of overheating risk and cooling need at room level for different levels of energy renovation, different residence types and different climatic conditions
- Analysis of the ability of existing ventilation systems to utilize the free cooling potential of outdoor air and to create comfortable conditions in combination with other passive measures.
- Analysis of the performance of existing operation and control strategies both in relation to establishing thermal comfort and to reduce cooling need
- Development of new ventilative cooling solutions to prevent overheating and to create thermal comfort under a wide range of climatic conditions
- Development of integrated control strategies for ventilative cooling and other passive measures to reduce overheating risk and cooling need
- Demonstration of the performance of ventilative cooling prototype solutions
- Development of simple guidelines assisting designers in reducing the risk for overheating

The project succeeded with the following main achievements and results:

- It was documented that overheating risk and cooling need at room level will appear in renovations, especially when energy performance levels after renovations is approaching requirements for new buildings. The risk is present in all European climates investigated (Denmark, Germany, UK and Austria)
- It was documented that existing ventilation systems with a limited air flow capacity (often corresponding to an ACR of $n=0,5\ h^{-1}$) cannot provide satisfactory cooling capacity, even if it is supplemented with short time manual window opening.
- It was documented that ventilative cooling is required during both day and night time to ensure comfortable conditions and that automatic control is recommendable.
- A new integrated and flexible control strategy for solar shading and ventilative cooling was developed that was able to ensure both thermal comfort and IAQ during the summer period, even if the mechanical ventilation was stopped.

It is expected that the project results will be lead to the following exploitations:

- The developed integrated control strategy has been implemented in the Smart Residence solution offered to the market by Visility (www.visility.com).
- New window solutions, including automatic control options that offer possibility of ventilative cooling during night and unoccupied hours, without increasing the risk of burglary, will be developed for the market
- A Danish guideline for ventilative cooling targeting house builders will be published
- The developed integrated control strategy has been implemented in the control strategy for a new prototype roof window with integrated solar shading and ventilation developed by VELUX in the EUDP project ”Det bæredygtige ovenlysvindue (J.nr. 64015-0020)”.
- The developed integrated control strategy has been implemented in the EUDP project ”Bolig 2020 med lavt energiforbrug og høj brugerkomfort (J.nr. 64015-0640)”, by Schneider Electric

1.4 Project objectives

Project hypothesis

Residential and office buildings are two very different building types both with regard to building and room geometry, building plan, building construction, time of occupation, heat loads, and possible complexity of solutions. The conclusions and recommendations on ventilative cooling performance and recommended solutions from literature is not applicable in a residential context and research is needed with regard to:

- Analysis of overheating risk and cooling needs in residences at room level
- Analysis of the ability and effectiveness of ventilative cooling to remove heat from building constructions depending on chosen air flow conditions (air distribution concept and velocity levels) and air flow rates
- Analysis of the ability and effectiveness of ventilative cooling to control the thermal environment within acceptable limits depending on chosen airflow conditions, air flow rates as well as operation and system control strategy.

Provided that this scientific basis is established, it will be possible to develop solutions that can provide cooling to residences and achieve an improved thermal comfort. The main challenge in the development phase is to develop solutions that fulfil all the other design constraints, like acceptable security, noise attenuation or reduction of pollution from outdoor, in a cost effective way.

Objectives

The objectives of this project were both to address the design challenges related to eliminating the cooling need and the risk of overheating in energy renovated residences under different climatic conditions - and to develop attractive ventilative cooling solutions for this building type.

The research objectives included:

- To analyse overheating risk and cooling needs in residences at room level and identify the controlling parameters
- To analyse of the ability and effectiveness of ventilative cooling to remove heat from building constructions and determine the key characteristics to fulfil
- To analyse of the ability and effectiveness of ventilative cooling to control the thermal environment and determine the operation characteristics to fulfil

The technical objectives of the project included:

- To map and evaluate the cooling performance of existing mechanical and natural ventilation systems and technologies for residences
- To extent the boundaries of existing ventilation systems in renovated buildings for effective ventilative cooling applications
- To develop new flexible and reliable ventilative cooling concepts.
- To develop effective control strategies for ventilative cooling solution
- To demonstrate the potential and importance of ventilative cooling performance through case studies.

Implementation

In order to fulfill the objectives the work was divided in a number of separate phases and work packages:

Initiation phase:

The work in this phase was driven by the companies and supported by AAU and it included

WP1: Mapping and characterization of typical ventilation system solutions and other passive cooling measures for residences will be carried out.

WP2: A number of potential case studies was analyzed and evaluated in relation to their suitability for WP 3-8. 4 case studies were selected for further studies

Analysis phase:

The work in this phase was mainly be carried out by AAU with input from companies.

WP3: Analysis included cooling need and overheating risk at room level in residences for different climatic conditions and different levels of energy renovation. The effect of other passive measures was also included. The results defined the needs for ventilative cooling and the market potential.

WP4: Analysis of ventilative cooling performance of the existing ventilation systems was carried out. The results identified shortcomings and development needs and defined key market segments.

WP5: Analysis of the performance of the operation and control strategies of existing systems was carried out. The results identified shortcomings and development needs.

Development phase:

The work in this phase was carried out in close cooperation between the companies and the university.

WP6: Concept solutions was developed and evaluated through predicted performance in selected case studies. The performance was compared and evaluated in relation to competitive technologies.

WP7: Integrated control strategies was developed and evaluated through predicted performance in the selected case study.

Demonstration and evaluation phase:

The work in the demonstration phase was driven by the companies and supported by Aalborg University.

WP8: In a case study (renovated residence) measured performance (energy use and comfort) was evaluated in relation to the chosen control strategy and the identified user practices and design assumptions.

WP9: Based on the obtained knowledge and results in the previous work packages a set of guidelines was developed for design and operation and published as part of an international design guide.

The project generally followed the initial plans and time-schedule.

1.5 Project results and dissemination of results

In the following the results is presented as the outcome of each workpackage.

WP1: Mapping and characterization of typical ventilation system solutions and other passive cooling measures for residences will be carried out. The outcome was a list of typical existing ventilation solutions for residences and their ventilative cooling potential.

WP2: A number of potential case studies was analyzed and evaluated in relation to their suitability for WP 3-8.

The starting point for the analysis was the "Typology Approach for Building Stock Energy Assessment -Tabula" project, which has a harmonized structure and describes analytically archetypes of 13 European countries, categorized in periods and building types (detached, terraced, apartments and multifamily buildings. The Tabula project focuses on residential buildings and suggests possible renovation scenarios based on the regulations of each country and the saving potentials of the existing buildings.

It was decided to select four case studies for the analysis representing four different climates and European countries. The selected countries were Denmark, France, Austria and UK as these represent the most important markets for VELUX and Dovista. The Danish and the South French case studies (representing more than 1.6 million dwellings in total) were real buildings from 1970s and 1980s respectively as extracted from the Tabula project. The Austrian and U.K. case studies (representing more than 1.7 million dwellings) were hypothetical average dwellings approximately from the middle of the previous century. The TABULA case studies were used and analyzed at the official reports of the examined countries to the European commission, and they are based on deep statistical analysis of the energy certificates.

In general, the case studies are heavy-weight constructions with materials and construction techniques of these periods. The insulation was placed inside the walls (foam insulation) and in the attic (mainly mineral wool). The dwellings have high thermal mass and high thermal bridging. In most of the dwellings, the window glazing is single and the frame is wooden. The opening percentage for every orientation is extracted from the sources. Table 1 presents the thermal (U-value and g-value) and technical characteristics of the examined dwellings (base case). Houses have no mechanical ventilation or active cooling systems.

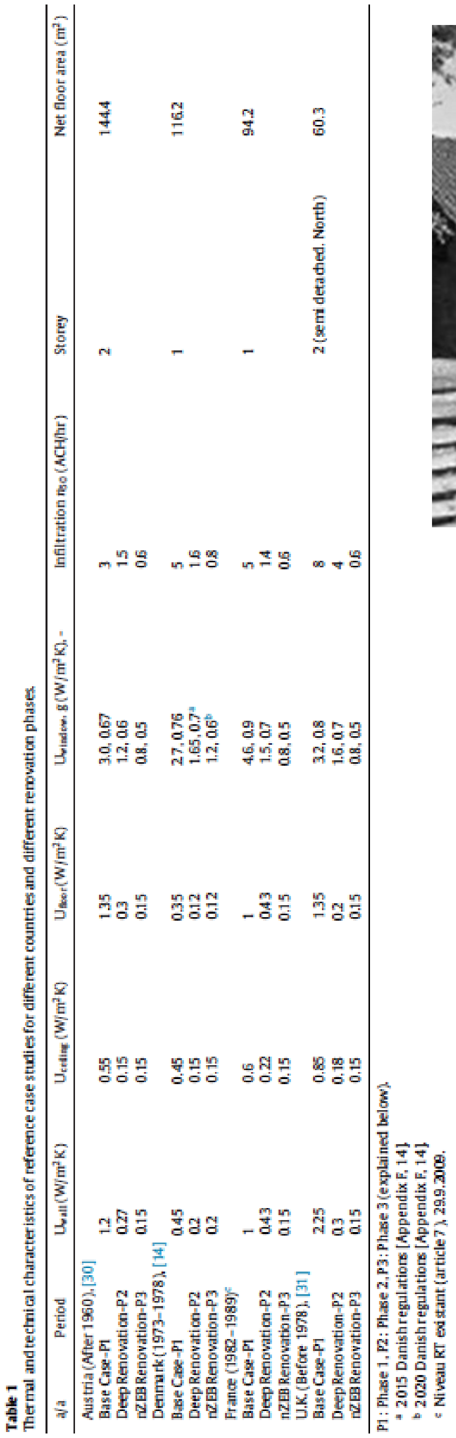


Table 1
Thermal and technical characteristics of reference case studies for different countries and different renovation phases.

a/a	Period	U_{wall} (W/m²K)	$U_{ceiling}$ (W/m²K)	U_{floor} (W/m²K)	U_{window}, g (W/m²K), -	Infiltration n_{50} (ACH/hr)	Storey	Net floor area (m²)
Austria (After 1960), [30]								
Base Case-P1		1.2	0.55	1.35	3.0, 0.67	3	2	144.4
Deep Renovation-P2		0.27	0.15	0.3	1.2, 0.6	1.5		
nZEB Renovation-P3		0.15	0.15	0.15	0.8, 0.5	0.6		
Denmark (1973–1978), [14]								
Base Case-P1		0.45	0.45	0.35	2.7, 0.76	5	1	116.2
Deep Renovation-P2		0.2	0.15	0.12	1.65, 0.7[a]	1.6		
nZEB Renovation-P3		0.2	0.15	0.12	1.2, 0.6[b]	0.8		
France (1982–1989)[c]								
Base Case-P1		1	0.6	1	4.6, 0.9	5	1	94.2
Deep Renovation-P2		0.43	0.22	0.43	1.5, 0.7	1.4		
nZEB Renovation-P3		0.15	0.15	0.15	0.8, 0.5	0.6		
U.K. (Before 1978), [31]								
Base Case-P1		2.25	0.85	1.35	3.2, 0.8	8	2 (semi detached. North)	60.3
Deep Renovation-P2		0.3	0.18	0.2	1.6, 0.7	4		
nZEB Renovation-P3		0.15	0.15	0.15	0.8, 0.5	0.6		

P1: Phase 1, P2: Phase 2, P3: Phase 3 (explained below).

[a] 2015 Danish regulations [Appendix F, 14].

[b] 2020 Danish regulations [Appendix F, 14].

[c] Niveau RT existant (article 7), 29.9.2009.

Table 1. The thermal (U-value and g-value) and technical characteristics of the examined dwellings (base case). Pictures shows from top to bottom, the Danish, Austrian, French Case, respectively.

WP3: Analysis of the four cases included cooling need and overheating risk at room level in residences for different climatic conditions and different levels of energy renovation. The effect of other passive measures was also included.

The applied renovation packages of the reference houses are divided into two categories: (1) the measures which refer to the efficiency of the elements (Group A) and (2) the measures which refer to the systems (mechanical ventilation, shading systems) of the building (Group B).

The renovation measures are also analyzed in three phases. The first phase will contain analysis of the initial base case study as extracted from the reports (symbol o in Table 2). The renovation targets of many countries coincide with the cost-effective measures for renovation due to the European Directive. In the second phase (symbol + in Table 2) the case studies are renovated, according to the regulations of each country (2013) in steps (Tables 1 and 2). The procedure is explained below:

- Replacement of windows.
- Improvement of the physical characteristics of the ceiling.
- Improvement of the physical characteristics of the external walls.
- Improvement of the physical characteristics of the floor.
- Improvement of the airtightness.

Typically, owners in real cases renovate dwellings for financially reasons in steps. The typical work flow and sequence of actions is the replace of the windows (less invasive renovation) then the insulation of the ceiling and the external walls and at the end the insulation of the floor elements (most invasive renovation). These renovations in many cases take months or years. The same approach is followed also in this research (Table 2). Every renovation variant has one or two additional renovation improvements compared to the previous one. With this work flow for every country they created 7–9 different renovation variants (Table 2).

The improvement of the airtightness of a building is a process related with all the stages of the renovation. The airtightness improvements are represented as a different variant because the authors would like to separately highlight the effect of this to the overheating risk of a building. The use of the external insulation systems instead of the internal systems is related with the decision for exploitation of the high thermal mass of the building (graphite EPS for the walls, mineral wool for the ceiling and high compressive strength XPS boards for the floor elements). The validity of the regulations of each country is outside the scope of this paper. The regulation targets were used only as intermediate steps into the energy efficiency.

In the third phase (symbol ++ in Table 2) of the simulations, the case studies (Tables 1 and 2), were renovated to reach very efficient energy goals (nZEB). The thermal characteristics of the envelope elements are based either on guidelines of Passive House standards2 or on the 2015 Danish building regulations.

In many cases the energy renovation of the house is accompanied with the installation of new mechanical ventilation systems with heat recovery for the diminishing of the winter ventilation losses (also higher capacity). In addition, in many cases, new efficient windows are accompanied with shading systems as a package. For the fulfillment of the analysis, two additional renovation packages, which prevent the increase of the overheating risk indoors, were analyzed (Table 3).

The systems above were applied in two out of four case studies (Denmark and South France), at the end of every phase (full compliance).

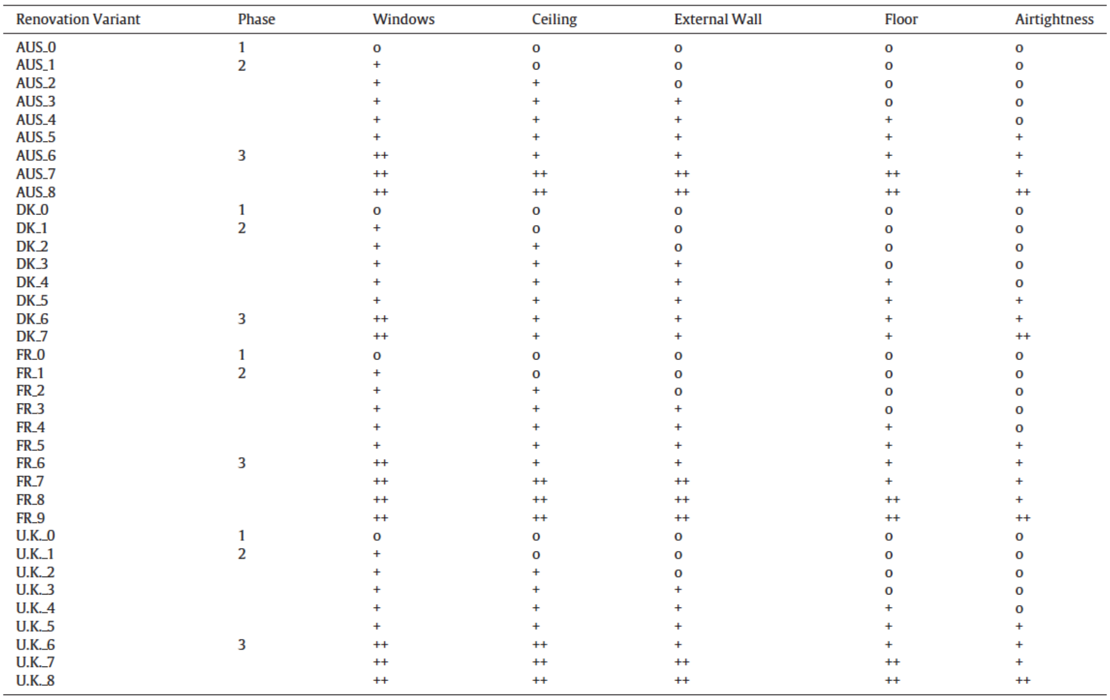
Three different shading systems have been analyzed:

- internal venetian blinds with high reflectivity (0.8)
- external slat blinds with high reflectivity (0.8) and
- fixed pergolas-awnings (0.5 m projected)

The movable shadings systems are applied to all the affected orientations and windows during the unoccupied hours.

The second examined measure simulated as an increase of the ventilation airflow rate from the basic value (0.5 ACH/hr for indoor air quality reasons) to 1.5 ACH/hr in two steps. Reduced ventilation flow below the value of 0.5 ACH/hr may cause a perception of impaired air quality in dwellings. The new rates are applied all day for every room. The constant use of the mechanical ventilation system is typical for a lot of new houses without control buildings systems, because the owners either do not want to be involved in the control of the house or do not understand how the systems work.

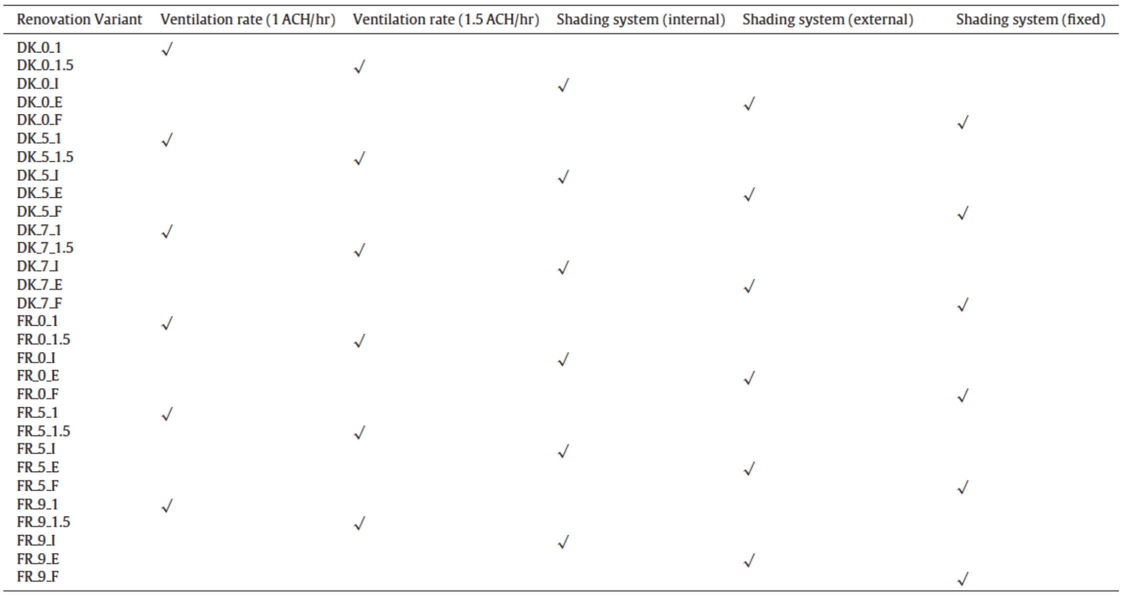
Table 2
Renovation packages (Group A) for reference case studies for different phases and locations.



Renovation Variant	Phase	Windows	Ceiling	External Wall	Floor	Airtightness
AUS_0	1	o	o	o	o	o
AUS_1	2	+	o	o	o	o
AUS_2		+	+	o	o	o
AUS_3		+	+	+	o	o
AUS_4		+	+	+	+	o
AUS_5		+	+	+	+	+
AUS_6	3	++	+	+	+	+
AUS_7		++	++	++	++	+
AUS_8		++	++	++	++	++
DK_0	1	o	o	o	o	o
DK_1	2	+	o	o	o	o
DK_2		+	+	o	o	o
DK_3		+	+	+	o	o
DK_4		+	+	+	+	o
DK_5		+	+	+	+	+
DK_6	3	++	+	+	+	+
DK_7		++	+	+	+	++
FR_0	1	o	o	o	o	o
FR_1	2	+	o	o	o	o
FR_2		+	+	o	o	o
FR_3		+	+	+	o	o
FR_4		+	+	+	+	o
FR_5		+	+	+	+	+
FR_6	3	++	+	+	+	+
FR_7		++	++	++	+	+
FR_8		++	++	++	++	+
FR_9		++	++	++	++	++
U.K._0	1	o	o	o	o	o
U.K._1	2	+	o	o	o	o
U.K._2		+	+	o	o	o
U.K._3		+	+	+	o	o
U.K._4		+	+	+	+	o
U.K._5		+	+	+	+	+
U.K._6	3	++	++	+	+	+
U.K._7		++	++	++	++	+
U.K._8		++	++	++	++	++

o stands for the initial base.
+ stands for the deep renovation.
++ stands for the nZEB renovation.

Table 3
Renovation packages (Group B) for reference case studies for different phases and locations.



Renovation Variant	Ventilation rate (1 ACH/hr)	Ventilation rate (1.5 ACH/hr)	Shading system (internal)	Shading system (external)	Shading system (fixed)
DK_0_1	✓				
DK_0_1.5		✓			
DK_0_I			✓		
DK_0_E				✓	
DK_0_F					✓
DK_5_1	✓				
DK_5_1.5		✓			
DK_5_I			✓		
DK_5_E				✓	
DK_5_F					✓
DK_7_1	✓				
DK_7_1.5		✓			
DK_7_I			✓		
DK_7_E				✓	
DK_7_F					✓
FR_0_1	✓				
FR_0_1.5		✓			
FR_0_I			✓		
FR_0_E				✓	
FR_0_F					✓
FR_5_1	✓				
FR_5_1.5		✓			
FR_5_I			✓		
FR_5_E				✓	
FR_5_F					✓
FR_9_1	✓				
FR_9_1.5		✓			
FR_9_I			✓		
FR_9_E				✓	
FR_9_F					✓

I: stands for internal shading system.
E: stands for external shading system.
F: stands for fixed shading system.

This work uses two well documented and widely applied indices for the assessment of the overheating indoors. The first index is referred to the EN15251 European adaptive method. The index measures the percentage of the occupied hours with operative temperatures higher than the upper bound of the adaptive comfort temperature. In our cases for renovated residences, Category II is been used. This category refers to normal level of comfort expectations and suggested from the standards for new buildings and renovations.

The second index measures the percentage of occupied hours with operative temperatures above fixed thresholds, 26 ◦C for bedrooms (building) and 28 ◦C for living room (static method). These benchmarks are not depended on any comfort model, are asymmetric and do not refer to any categories.

In this report only the results of the Danish case is reported.

Fig. 1 presents the percentages of occupied hours with overheating for both methods, different renovation packages, rooms for the Danish Case. Danish regulation for costoptimal retrofit goals was set at the end of 2010 in parallel with the adoption of 2015 and 2020 goals (new buildings). The 2020 energy goals of phase 3 for the particular Danish house may be succeeded with measures related with the improvements of the airtightness and the glazing. These renovation measures are antagonistic in terms of overheating risk. As a result the outputs of the analyses are almost coinciding (variants 5 and 7). For these cases the deviation of the methods is important for every phase and package.

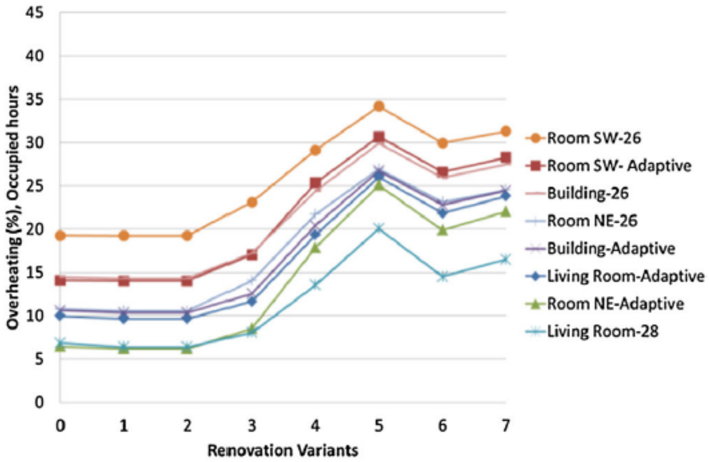


Fig. 1. Percentage of overheating hours (occupied) for different renovation variants (Table 2) in room level for both methods, for the Danish case study.

Fig. 2 presents the results for different occupancy levels, assessed by two methods for the two climatically extreme case studies. The decrease in overheating occurrences for different phases of renovation is from 2.9% to 8.6% (in relative terms) for dynamic method and from 3.2% to 6.8% for static method for the Danish house. The adaptive method seems to be more sensitive to different internal loads (occupancy and equipment). Finally, the more efficient the building, the more important the role of the internal loads to the assessment of overheating risk.

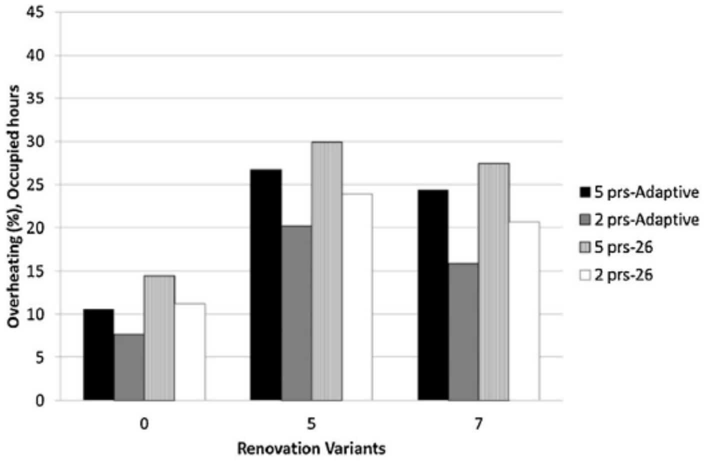


Fig. 2. Percentage of overheating hours (occupied) for different renovation variants (Table 2) and occupancies for both methods, for the Danish case study.

Fig. 3 presents long-term overheating risk indices for different renovation variants and ventilation air changes for both methods. In general, the increase of the ventilation air change dramatically decreases the overheating occurrence indoors. The higher the efficiency of the building, the higher the effectiveness of the measure. In the Danish house both methods show similar outputs.

A lot of designers of high efficient buildings suggest to the owners the increasing of the air changes of the mechanical ventilation systems during the transition and summer periods (no use of windows). The constant operation of the system during the whole day increases slightly the energy consumption of the house but guarantee excellent indoor conditions in terms of air quality and acceptable limits of overheating. Various researchers have analyzed in depth the constraints and limitations of the manual use of the windows of a house.

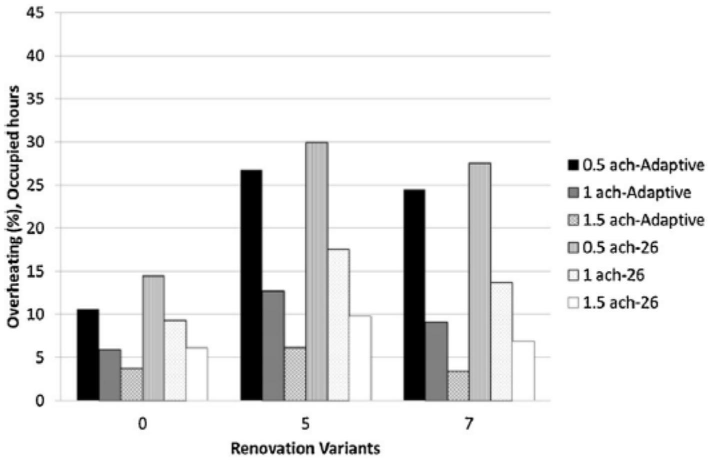


Fig. 3. Percentage of overheating hours (occupied) for different renovation variants (Table 2), methods and ventilation rates, for the Danish case study

As far as the shading analysis (Fig. 4) goes, the use of external movable blinds or fixed systems decreases the indices approximately 50% in the Danish case for both methods. The application of the internal blinds decreases the occurrence by approximately 25%. The two most efficient shading systems seem to have similar results for both methods.

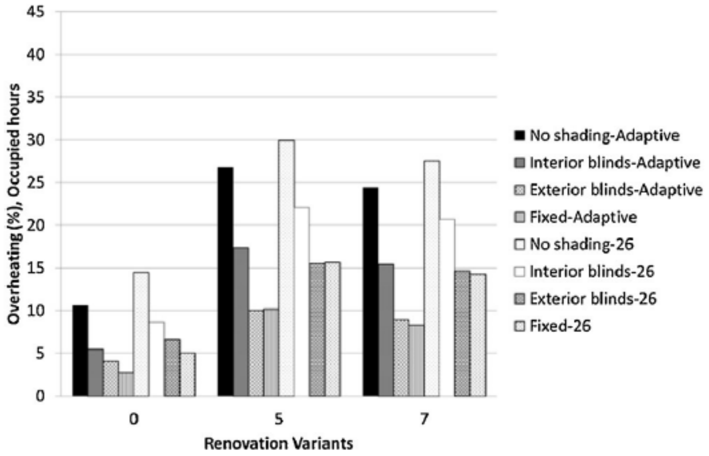


Fig. 4. Percentage of overheating hours (occupied), for different renovation variants (Table 2), methods and shading systems, for the Danish case study

The results of the analysis documented the risk of overheating in renovation cases, but also showed that both solar shading and ventilation are effective measures.

WP4 and WP5: Analysis of ventilative cooling performance of the existing ventilation systems as well as the performance of the operation and control strategies of existing systems was carried out. Five different ventilative control strategies were examined.

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. 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 work as “typical” representative manual use (Table 4).

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

Table 4. Typical manuel opening strategies.

The manual opening is applied to all the windows of the case study, independently of the outdoor environmental conditions during the examined period. For the first two control strategies, overheating was calculated also with the application of different shading systems (drapery, internal/midpane/ external blinds with high reflectivity) for intercomparison reasons. The shading systems were applied only during the non-occupied period 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 4), 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 12.5oC) 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 22oC to avoid undercooling incidents. This value is the result of desk sensitivity analysis (not presented here) 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.

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. 5). Similar results are presented also for manual control of openings (23.6% and 25.6% respectively-Fig. 6).

The use of different shading systems significantly decreases the overheating occurrences for both control strategies and renovation scenarios (Figs. 5 and 6). 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 energy efficient scenario presents higher overheating risk.

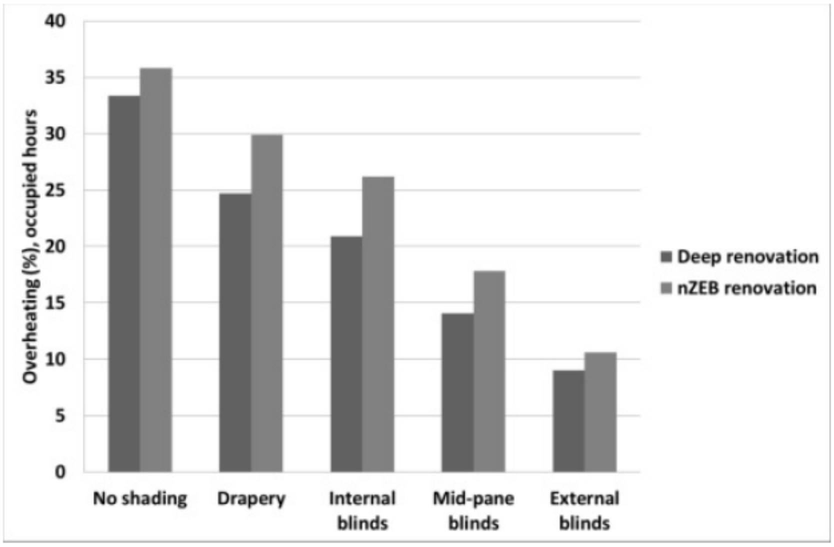


Fig. 5 Overheating assessment (%) without or different shading systems and ventilative cooling through mechanical systems (two renovation scenarios)

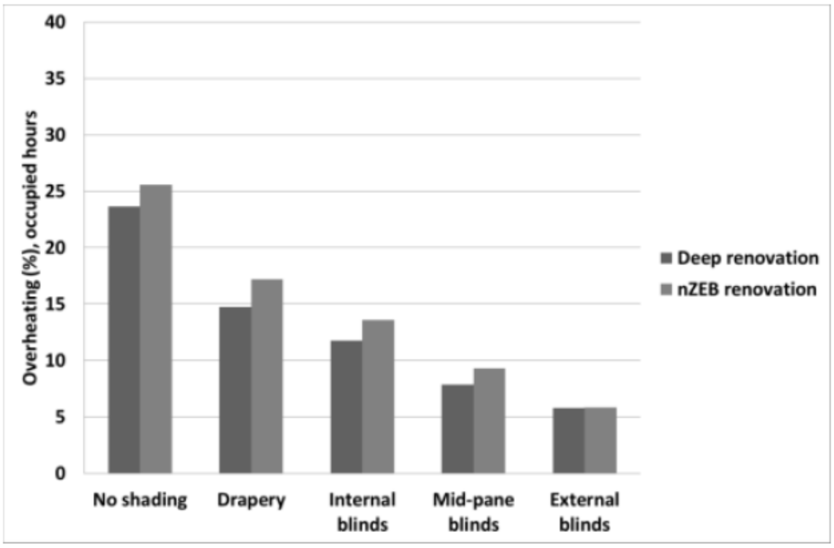


Fig. 6 Overheating assessment (%) without or different shading systems and manual control of the windows (wind effect, discharge coefficient: 0.65 and window opening: 10%, two renovation scenarios)

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. 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

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%.

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.

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. Ventilative cooling controlled by automated systems are more effective to more efficient houses.

WP6: Concept solutions was developed for ventilative cooling and evaluated through predicted performance in selected case studies.

Figure 7 present the effectiveness (average, maximum, and minimum values) of every examined automated control strategy compared with the basic examined ventilation patterns (mechanical ventilation and manual window opening), for different case studies and renovation scenarios for the total of the analysis. On average, for the Danish case, the effectiveness of the automated control strategies is higher than 80% (for all the cases) and 90% for 10 out of 12 cases (21). For the French case, the effectiveness (average value) is over 70% (for all the cases).

The comparison of the results among the manual window opening and the mixed automated control strategy highlights the importance of the night ventilative cooling in the design of an energy renovated house without overheating risk.

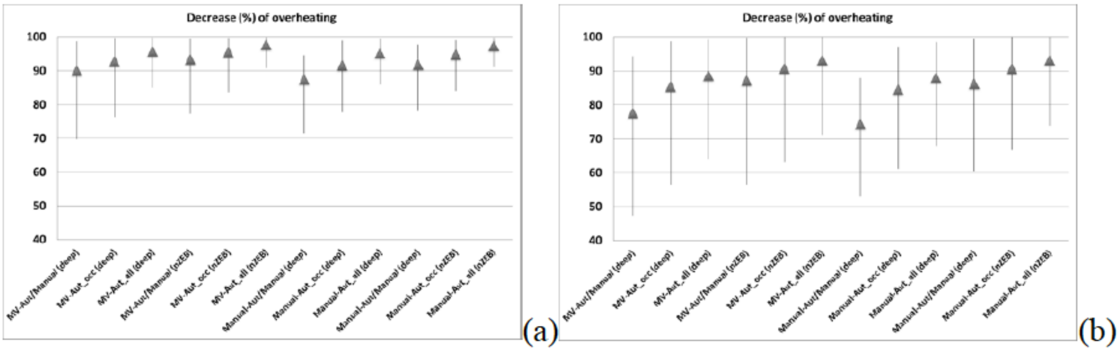


Figure 7 Effectiveness (decrease of overheating, %) of different automated control strategies for two renovation scenarios for the total of the analysis, a: Danish dwelling and b: South French dwelling, (minimum, average, and maximum values; manual: manual window opening, MV: mechanical ventilation, aut: automated window opening, occ: activated during the occupied hours, all: activated during all-day, deep: deep renovation scenario, nZEB: nZEB renovation scenario).

WP7: Integrated control strategies was developed and evaluated through predicted performance in the selected case study.

The control strategy integrate three functions for user activation:

- Cooling (Ventilative cooling)
- Indoor air quality
- Shading

for the three occupancy states: non-occupied, occupied and night. Occupancy states change by the user or by schedule (morning and night time) and refer to a specific zone. The user decides which functions to activate for every occupancy state and zone (possible simultaneous activation, Figure 10b). In addition, user sets the thresholds for 4 environmental parameters and the time interval of the algorithm (Figure 10a):

- Indoor natural ventilation cooling temperature. Set point range: 18-30o C
- Indoor temperature for shading. Set point range: ±3o C relative to indoor-natural ventilation cooling temperature
- Carbon dioxide. Set point range: 400-2000ppm
- Relative humidity. Set point range: 50-90%
- Time interval for control action. Range: never, 10 minutes-4 hours

In addition, users have the possibility to check the environmental parameters of thecurrent day for every zone separately (Figure 10c). Special signals for out of the limits environmental values show up for informative reasons (Figure 10d).

Users have the possibility to override (increase, decrease, close or open) or to deactivate the window system at any time during the day (time interval). The three functions of the control strategy are presented below:

- **Cooling function.** Connected windows of the zone open when the outdoor temperature is lower than the indoor operative zone temperature and when the indoor zone temperature is over the indoor natural ventilation cooling temperature set point, incrementally (10%/25%/50%/75%/100% of the window actuator). After a time interval and if the indoor zone temperature is higher than the previous value, windows step to the next increment (if not, windows stay unchanged). The maximum allowed temperature difference between indoor and outdoor is 10o C (draft reasons).
- **Indoor air quality function.** Connected windows of the zone open when the carbon dioxide concentration (ppm) or the relative humidity (%) is over the set point (also outdoor absolute humidity plus an error factor is lower than the indoor), incrementally (10%/25%/50%/75%/100% of the window actuator). Between the two environmental parameters, carbon dioxide concentration is prioritized as the most important factor for window opening (indoor air quality function). The maximum accepted temperature difference between indoor and outdoor temperature is 10o C and 5o C for colder and hotter outdoor conditions respectively. For parallel use of indoor air quality and cooling functions, the algorithm prioritized the cooling function for indoor operative temperatures over the indoor natural ventilation cooling temperature set point and the indoor air quality function for indoor operative temperatures below this set point.
- **Shading function.** The connected shading system, internal or external, is fully activated (open-close function) when the indoor operative temperature is over the shading temperature set point and the solar radiation affects the specific window (over 10o solar height and ±60o solar azimuth compared with the window orientation).

Figure 8 illustrates the algorithms implemented for the control strategy developed.

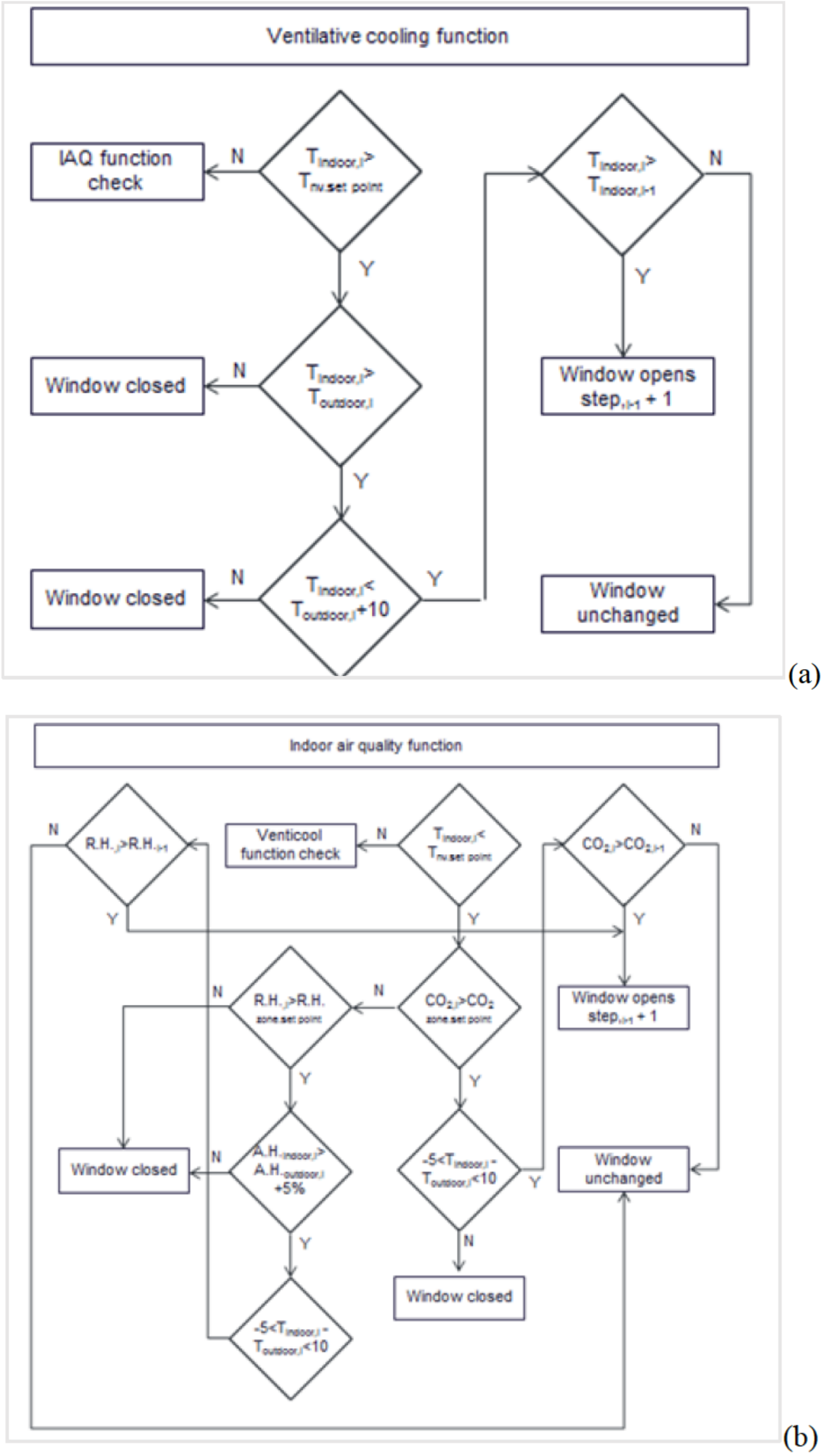
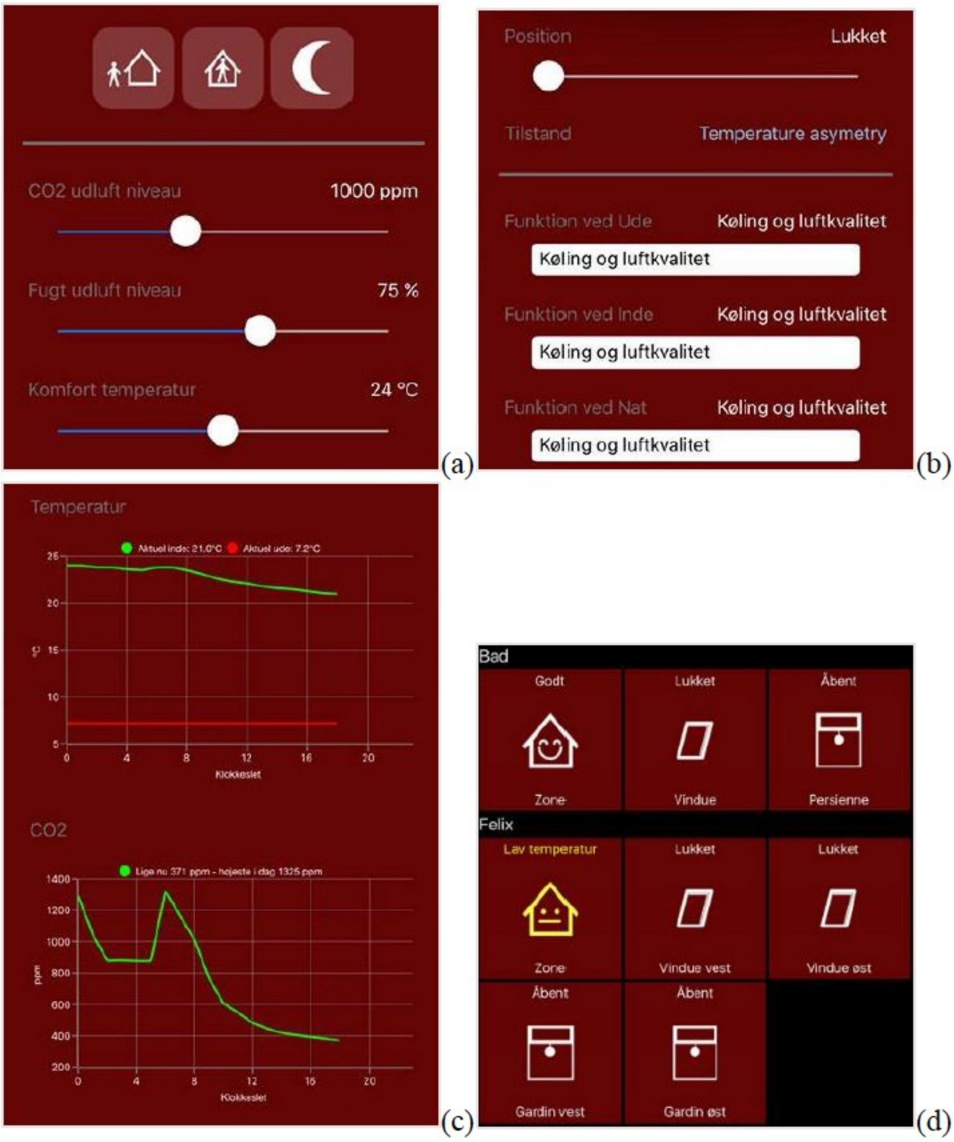


Figure 8 Algorithms for a: ventilative cooling and b: indoor air quality function of the window system. (T: operative temperature (oC), Tnv.set point: indoor natural ventilation cooling temperature set point (oC), CO2: carbon dioxide concentration (ppm), R.H.: relative humidity (%), A.H.: absolute humidity, and i: step i, Y: yes and N: no).

Figure 9 Gateway of the window system (Visility ApS).



CO2 udluft niveau 1000 ppm

Fugt udluft niveau 75 %

Komfort temperatur 24 °C

(a)

Position Lukket

Tilstand Temperature asymetry

Funktion ved Ude Køling og luftkvalitet

Køling og luftkvalitet

Funktion ved Inde Køling og luftkvalitet

Køling og luftkvalitet

Funktion ved Nat Køling og luftkvalitet

Køling og luftkvalitet

(b)

(c)

Bad

Godt / Zone

Lukket / Vindue

Åbent / Persienne

Felix

Lav temperatur / Zone

Lukket / Vindue vest

Lukket / Vindue øst

Åbent / Gardin vest

Åbent / Gardin øst

(d)

Figure 10 Screenshots of the developed mobile application of the window system a: user set points of the environmental parameters, b: activated functions for every occupancy state, c: monitoring of the environmental parameters of the current day, and d: general overview of the application (Visility ApS).

WP8: In a case study (renovated residence) measured performance (energy use and comfort) was evaluated in relation to the chosen control strategy and the identified user practices and design assumptions.

The examined residential building is a yellow brick, two-storey detached dwelling from 1937 and located in a suburban area North of Copenhagen, Denmark (Figure 11). The house is 172.4 m2 (gross area) and 363.3 m3 (net volume area) with a basement. The dwelling is occupied by a working family, four members in total. This building is representative of the Danish residential building stock.

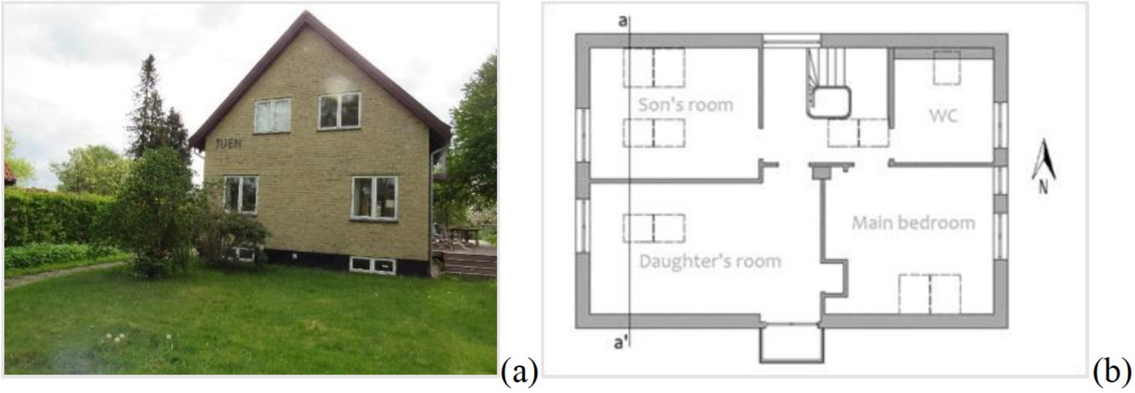


Figure 11 West side view of the a: examined case and b: floor plan of the upper floor.

The building was renovated in various steps. In 2006, the ground floor (over the-basement) and the external walls (foam inside the bricks) were insulated and heating system (gas) was installed. The total rebuilt of the roof was started in 2013 and finished in 2014, with new wooden floor with insulation, roof insulation (mineral-wool) and vapor barriers (Figure 12), and installation of eleven pivot roof windows (nine with motors and electrically driven actuators, Figure 13 (a-c)). The roof windows were installed in the bathroom (1), the three bedrooms (6), and the stairway corridor. The roof windows (apart from those in the corridor) have integrated automated external shading systems (South orientation) and internal blackout blinds (Figure 13 (b, c)). Façade windows are wooden with double glazing (side -hung). There is a small balcony on the South facing façade (Figure 11a). Façade windows integrate light-white curtains, rollers, and venetian blinds (Figure 11a). The doors are also wooden.

Figure 12 Renovation of the external wall and roof of the case stuydy.

Balanced mechanical ventilation system, temperature controlled, with heat recovery (maximum 86%) is installed also in the house. The maximum airflow rate is approximately 0.9 ach. The mechanical ventilation system was deactivated during the summer of 2016. The opening and the use of the shading systems of the façade windows is totally manual. For 2016, these elements (manually controlled) were "out-of- use" based on the suggestions of the research team. Roof windows control during the summer of 2015 was manual and supported by an electronically assisted system. The system was based on time schedules set by the users (purge ventilation every 15 minutes for 4 times per day and others). The control of the motorized roof windows (window opening and shading system activation) for summer period of 2016 was totally automated. Rain sensors support the function of the window system, in case of strong rainfall.

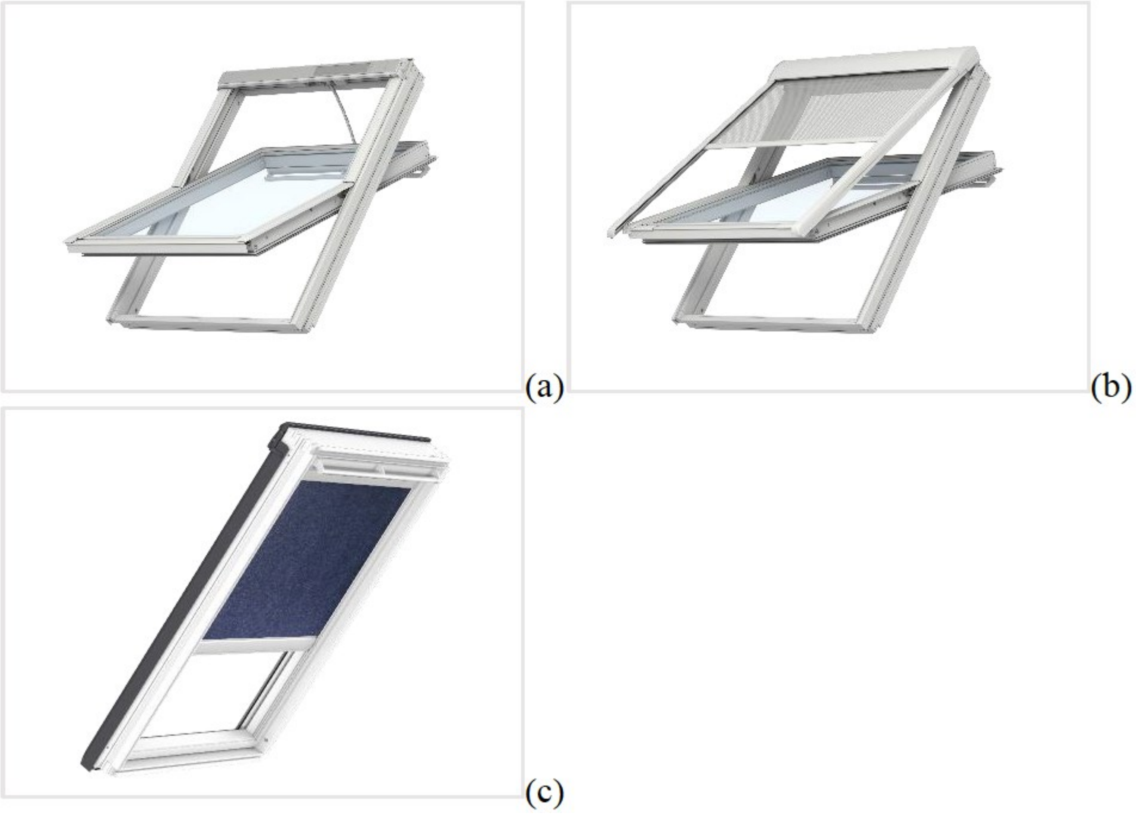


Figure 13 Roof windows a: with actuators, b: external, and c: internal shading systems.

The upper floor of the dwelling (Figure 11b) was monitored from 19 May 2015, and the rooms of the ground floor (living room and kitchen) were monitored from 18 May 2016. For every examined room, the temperature (° C), the carbon dioxide concentration (ppm), and the relative humidity (%) have been continuously monitored with calibrated sensors encapsulated in silver plastic boxes (5-minute intervals), as well as the ambient temperature and relative humidity (externally). The sensor was installed externally of the house totally protected from solar radiation under the extension of the roof eave (Figure 11a). The sensors inside the dwelling were installed in places to avoid solar radiation and heat equipment or appliances, approximately in bed heights.

The thermal comfort assessment of the indoor environment for the 2015 and 2016 summer periods of the dwelling includes two metrics (dynamic and static) and criteria. The first one is the POR index (Categories I and II; 28) and the second one is the exceedance index with two static benchmarks, 27o C and 28o C.

Figures 14 (a-d) present the percentage of hours (%), from June to August, with thermal discomfort (overheating and undercooling) for all the rooms of the upper floor (2015 and 2016) and living room and kitchen of ground floor (2016) for both Categories I and II.

Four out of five rooms of the upper floor presented overheating incidents in summer 2015, assessed with the criteria of Category II (Figure 14a). The highest values of the index (over 3%) are presented for the main bedroom and the daughter's room. These rooms are located at the Southern orientation and have high number of openings. The undercooling incidents were insignificant. The thermal discomfort of the upper floor in total, only overheating incidents, was less than 2%. All the rooms and floor in total managed to fulfill the requirement of the comfort Standard (5%). Thermal comfort assessment based on Category I for 2015 (Figure 14b) indicates that all the monitored rooms have both overheating and undercooling incidents with values higher than 5%. All the examined spaces did not fulfill the requirement of the comfort Standard. The main bedroom and the daughter's room present the highest thermal discomfort. The thermal discomfort of the floor in total is close to 6%. In terms of thermal comfort, the floor in total assessed as Category II for 2015. Overheating incidents for the examined bedrooms are possible in all the calculated running mean outdoor temperatures (Category I) and over 16o C for Category II. Undercooling incidents are significant mainly between 13.5o C and 18.5o C (Category I, all examined bedrooms). Overheating is possible in lower than 27o C indoor operative temperatures (main bedroom, Categories I and II).

For summer 2016, there is almost no overheating incidents (apart from living room) in all the examined rooms (Category II, Figure 14c). Undercooling (under 3%) is the only thermal discomfort for this period. The most discomfort spaces are the son's room and the main bedroom, around 2%. Floor thermal discomfort is 0.3% (only undercooling incidents). Thermal comfort assessment for 2016 (Figure 14d, Category I) indicates that four out of seven examined rooms have overheating and undercooling incidents. Rooms with only undercooling incidents oriented to the North (Figure 14b). In addition, four out of seven of the examined rooms have values higher than 5%. The most discomfort rooms are the corridor (only undercooling incidents) and the main bedroom (higher than 10%). The overheating is insignificant (less than 1%).

The corridor and son's room show higher values compared with 2015 (undercooling incidents instead of overheating). In total, floor and house in terms of thermal comfort belong to Category I. For 2016, the thermal comfort hierarchy of the examined rooms is not identical for both Categories, as it is for 2015. For the ground floor, the living room fulfills the requirements of Category I and the kitchen the requirements of Category II (only undercooling). These spaces were not monitored during 2015 for comparison of the outputs. The living room has similar discomfort incidents in comparison with the daughter's bedroom of the upper floor (similar orientation). On one hand, the living room has more heat gains compared to the daughter's room, but on the other hand, the living room has significant thermal mass (walls) for heat storage and shaded more during the day.

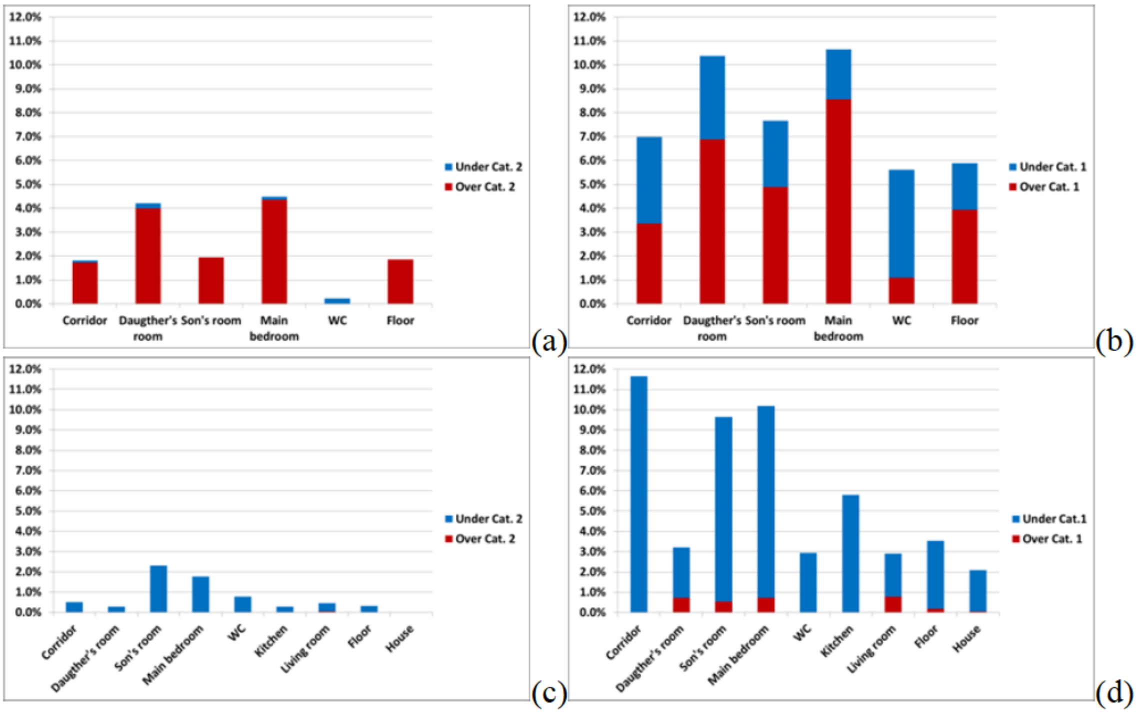


Figure 14 Thermal discomfort assessment (adaptive method, %) in room, floor, and house level of the dwelling for summer of 2015 (a, b) and 2016 (c, d), and Categories I (b, d) and II (a, c).

For bedrooms, there is overheating in running mean outdoor temperatures over 18oC (Category I) and indoor operative temperature over 26oC (Category I). Undercooling incidents show up in all calculated running mean outdoor temperature values (both Categories). Figure 15 highlights the overheating incidents (number of hours, both metrics and criteria) for the three bedrooms of the dwelling during night time (23:00-07:00) for both periods (2015 and 2016). The overheating incidents during night for 2016 are insignificant.

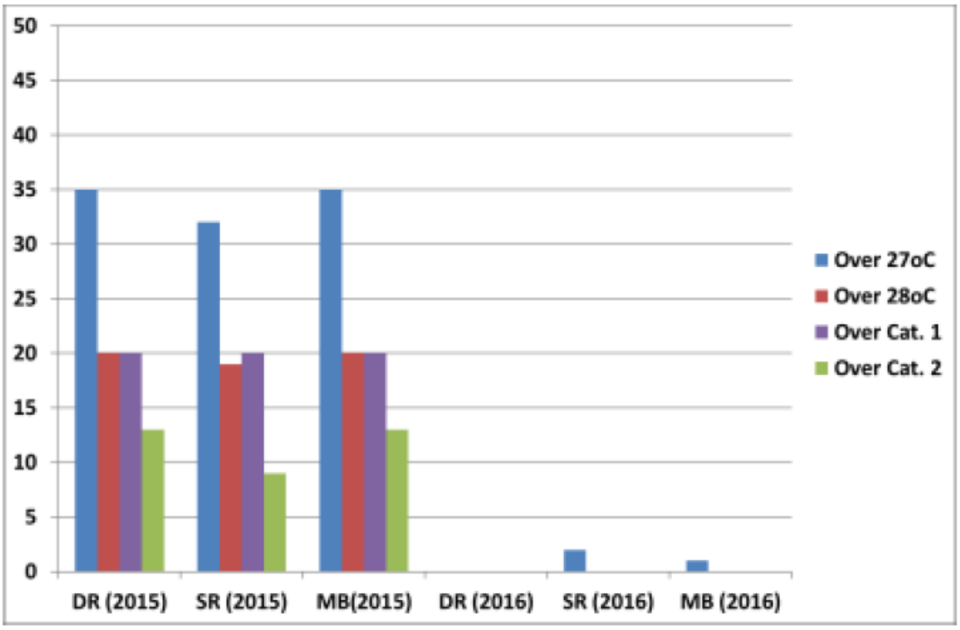


Figure 15. Number of hours (h) with overheating incidents, assessed by both metrics and criteria, for the three examined bedrooms (DR: daughter's room, SR: son's room, and MB: main bedroom) for 2015 and 2016 at night (23:00-07:00).

All the examined rooms present lower operative temperatures on average (also peak values) in 2016 compared with 2015 (apart from W.C.). The maximum indoor operative temperature for 2015 is presented in the main bedroom (31.6oC) and for

2016 in all 3 bedrooms (28.1oC). The minimum indoor operative temperature for 2015 is presented in the corridor (19.0oC) and for 2016 in the son's room (18.7oC). Most of the examined rooms have lower minimum indoor operative temperature in 2016 compared with 2015.

Figures 16 (a, b) show that thresholds (27oC and 28oC) are exceeded for more than 100 and 25 hours respectively for all three bedrooms in 2015. The corridor has exactly 100 hours over 27oC in 2015. The second requirement (maximum 25 hours above 28oC) is not fulfilled in any room of upper floor for 2015. For 2016, all rooms of the upper and ground floors fulfill both thresholds and fulfill the requirements of the regulation (Figure 16b). The highest overheating incidents are in the main bedroom and daughter's room (upper floor), for both years (assessed by 27oC threshold). The living room also shows high overheating incidents (2016). For 2016, the corridor and kitchen (North oriented, Figure 11b) show no overheating incidents (assessed by 27oC threshold). The incidents, assessed by 28oC threshold, for 2016 are insignificant.

The hierarchy of the bedrooms in terms of overheating is similar for both thresholds in 2015. The upper floor, in total, does not fulfill the requirements of the regulation for 2015: 106 and 65 hours respectively. Overheating incidents, in floor and house level, for 2016 are 20 and 17 respectively (assessed by 27oC threshold). No hours over 28oC are calculated, in floor and house level, respectively (Figure 16b).

Static and dynamic performance indicators and metrics cannot be compared directly because they assess different discomfort conditions. The static metric fails to highlight the undercooling risk that exists in many rooms during the peak summer period. Both metrics highlight the rooms with the highest overheating risk. The undercooling risk in bedrooms during hot summer periods (night) has to be investigated in the future.

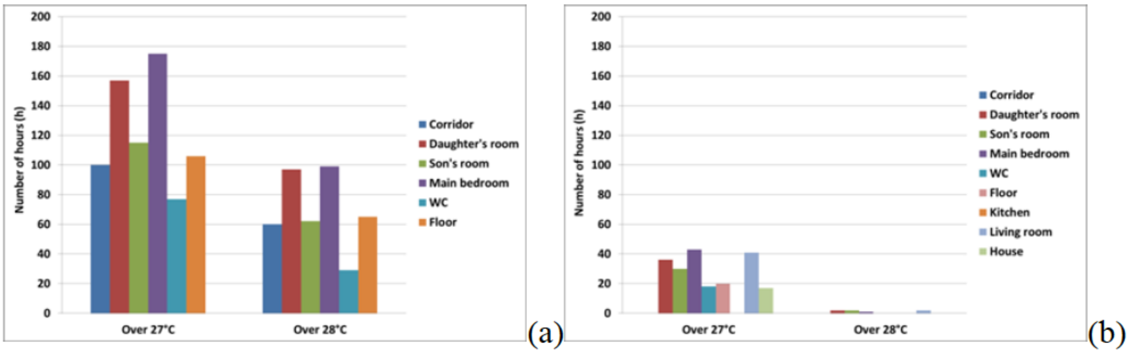


Figure 16 Number of hours (h) over 27oC and 28oC for all the examined rooms for a: 2015 and b: 2016.

Indoor air quality is assessed for every examined room based on comfort Standards (static thresholds) and national Danish regulations. The Danish Building Institute also suggests maximum acceptable relative humidity of the indoor spaces: less than 1% of the time over 75% relative humidity. In general, thresholds of comfort Standards are not applicable to residential buildings (indoor air quality).

As far as the carbon dioxide concentrations are concerned, all the bedrooms do not fulfill the requirements of Category II, apart from the main bedroom (2015, Figure 17a). In 2016, the daughter's room has slightly better indoor environment, compared with 2015 (Category I and II, Figure 17b). The opposite condition is assessed for the son's room. The indoor environment in the main bedroom is comparable for both periods.

As far as the relative humidity is concerned, all the bedrooms do not fulfill the requirements of Category II (both years. In addition, all rooms, W.C. included, fulfill the requirement of the national regulation for both periods. The maximum value for relative humidity for 2015 is 82% and for 2016 is 78%.

Window system effectiveness, in terms of air quality, during peak summer period is straight comparable with small deviations to the performance of the combined use of the mechanical ventilation system and the manual use of the façade and roof windows.

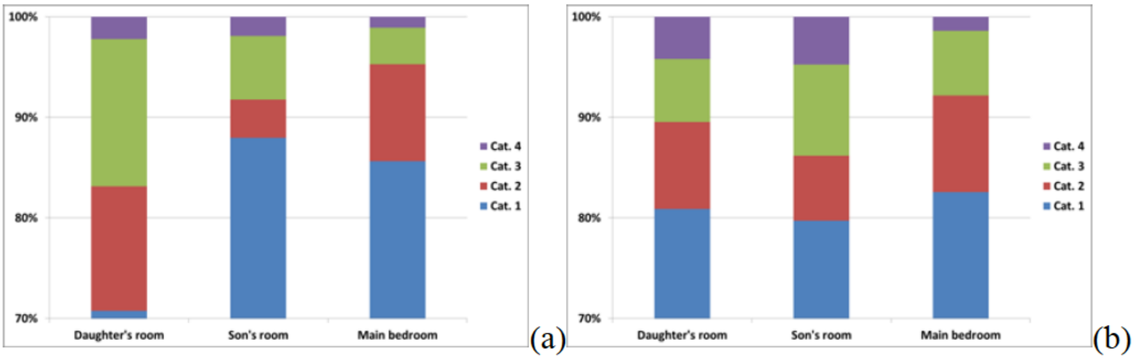


Figure 17 Indoor air quality assessment (carbon dioxide (ppm), Categories I, II, III, and IV) for the three examined bedrooms, for summer a: 2015 and b: 2016.

Table 6 presents the user set points of the window system for all the examined rooms during summer 2016. The set points were constant and did not differentiate significantly with the outdoor conditions. Occupants tried to solve local thermal, air quality and glare problems with manual overrides of the window system. Time intervals for control actions were from 10 minutes to 1 hour, but mainly 30 minutes.

Table 6 User set points of the environmental parameters of the window system, for different rooms (summer 2016).

	Corridor	**Daughter's room**	**Son's room**	**Main bedroom**	**W.C.**
Indoor natural ventilation cooling temperature (°C)	24 (June: 22)	24	24 (June: 23)	24	24
Indoor temperature for shading (°C)	-	0÷2	0÷2	-3÷2	-
Carbon dioxide (ppm)	1000	1000	1000	800	1000
Relative humidity (%)	60	60	60	60 (June: 50)	60-70

The monthly mean comfort temperatures were 24.6o C for June, 24.7o C for July and 24.2o C for August. These temperatures were higher than the used indoor natural ventilation cooling set point (24o C maximum) for every room. This action indicates that occupants in bedrooms in heating dominated temperate climates feel more comfortable with temperatures lower than those proposed by the comfort Standards.

Undercooling incidents were not a reported issue from any occupant of the house during summer 2016. A number of undercooling incidents for the corridor and the son's room were monitored in June when the set points for ventilative cooling were minimum (22o C and 23o C respectively).

The main bedroom also had comparable minimum set points for indoor air quality function (carbon dioxide concentration during all period and relative humidity in June). Occupants of two out of three bedrooms (apart from son's room) deactivated the window system during night because of noise nuisance from the actuator. Instead, the users were used to set a fixed window opening percentage, sometimes also 100%, for the whole night period (Figures 18 (a, b)). This action resulted also in a number of undercooling incidents (9 hours outside the limits of Category II and 14 hours outside the limits of Category I, Figure 18a). Minimum windows opening percentages for indoor air quality reasons are suggested for summer nights with low outdoor conditions, e.g. maximum 10o C difference between indoor and outdoor temperatures.

The non-automated use of the windows during night occasionally affects the indoor air quality of the bedrooms (humid environment) and causes unnecessary operation of the system the next couple of days (Figure 18a). In general, thresholds proposed for relative humidity assessment are not applicable, by definition, to residential buildings. The relative humidity control of the indoor air quality function of the window system suggested to be active only on specific rooms with severe violations.

A different user time interval for the indoor air quality function (smaller) on one hand helps the thermal optimization of the space, but on the other hand increases the complexity of the system. The morning and night set points of the occupancy states varied considerably during the total examined period for all the examined rooms.

The activation of the external shading system (manual override) during daytime would decrease the overheating risk to the minimum. The deactivation of the shading systems is a common process for these climatic conditions (visual contact with the outdoor environment). Typically, the shading systems are used in bedrooms to avoid the early morning sun.

The window system is active only when it is absolutely necessary to improve the indoor environment of the dwelling with minimum energy use for the motors. The energy use of the mechanical ventilation systems for this period (June to August 2015) would be approximately 220.8 kWh (for typical air change rates). The energy use of the window system for the same period (2016) was 10.1 kWh (95.4% energy savings). The energy savings from the deactivation of the mechanical ventilation system add extra value to the performance of the window system. The use of the window system may be extended also during the transition months and heating season.

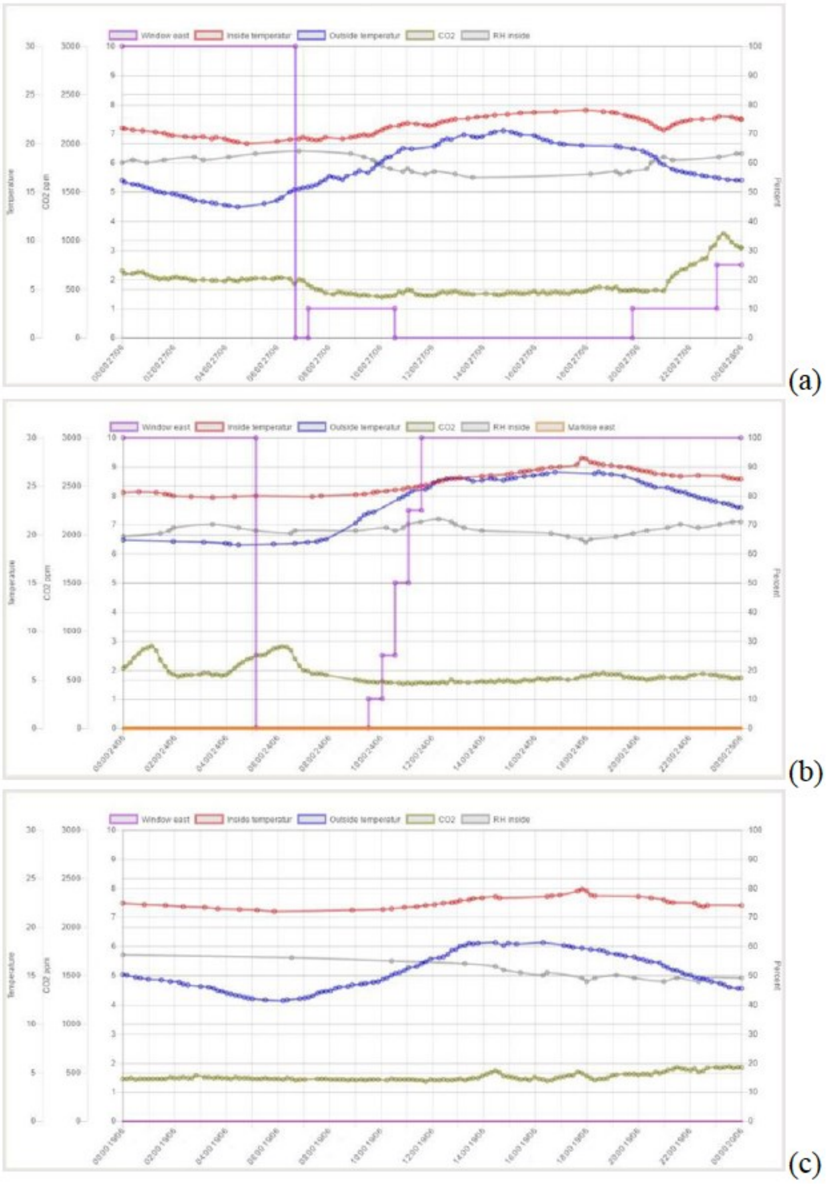


Figure 18 Daily indoor environment (temperature: oC, carbon dioxide concentration: ppm, and relative humidity: %) and use of windows and shading systems (%) for different rooms (a: main bedroom, b-c: daughter's room, Visility ApS;).

WP9: Based on the obtained knowledge and results in the previous work packages a set of guidelines was developed for design and operation. They include guidelines for reducing the risk of overheating and for application of ventilative cooling in renovated buildings, suggestions to improve the ventilative cooling capacity of existing ventilation systems in residential buildings, new reliable ventilative cooling concepts and control strategies for residential buildings and documented performance of ventilative cooling systems in case studies under real use.

The general applicable part of the developed design guidelines for ventilative cooling has been implemented in the Ventilative Cooling Design Guide published by IEA EBC as an official deliverable of EBC Annex 62 Ventilative Cooling.

A special version in Danish focusing on the specific conditions for single family houses in Denmark is under development.

The project succeeded with the following main achievements and results:

- It was documented that overheating risk and cooling need at room level will appear in renovations, especially when energy performance levels after renovations is approaching requirements for new buildings. The risk is present in all European climates investigated (Denmark, Germany, UK and Austria).
- It was documented that existing ventilation systems with a limited air flow capacity (often corresponding to an ACR of $n=0,5\ h^{-1}$) cannot provide satisfactory cooling capacity, even if it is supplemented with short time manual window opening.
- It was documented that ventilative cooling is required during both day and night time to ensure comfortable conditions and that automatic control is recommendable.
- A new integrated and flexible control strategy for solar shading and ventilative cooling was developed that was able to ensure both thermal comfort and IAQ during the summer period, even if the mechanical ventilation was stopped.

The results from the project have stimulated in significant degree to utilize the potential of a simple technology. The effects are to be seen in a longer perspective where the project has had important influence on documenting the effects. This information is feeding into product development, development of European Standards and input to compliance evaluation. All of this is expected to increase the demand for product solutions for ventilative cooling based on the findings of the project. Both VELUX and DOVISTA plan to introduce new products on the market in 2018 and 2019 in Denmark and other European countries, utilizing the results of the project to offer solutions for ventilative cooling.

The project results have been disseminated in the REHVA Journal, see reference list, which is distributed to the HVAC industry in 27 countries in Europe. Project results has also been presented at the following events:

1. Control strategies for ventilative cooling of overheated houses (Theofanis Psomas). 12th REHVA World Congress, Aalborg, Denmark. Aalborg University; 2016.
2. Analysis And Comparison Of Overheating Indices In Energy Renovated Houses (Theofanis Psomas). Building Simulation Conference 2015, Hyderabad, India, December 7.
3. Automated window systems to address overheating risk on deep renovated dwellings (Theofanis Psomas). 38th AIVC – 6th TightVent – 4th venticool conference, Nottingham, UK. September 2017.
4. Ventilative Cooling in Standards and Regulations, Country Report from Denmark (Karsten Duer). International Workshop on Ventilative Cooling Need, Challenges and Solution Examples. Brussels, Belgium, 19- 20 March 2013

1.6 Utilization of project results

The developed integrated control strategy has been implemented in the Smart Residence solution offer to the market by Visility (www.visility.com).

The results are already being utilized for the development of improved and new European Standards. VELUX product offerings will in the near future include products with controlled ventilative cooling – the project has added to this development.

Based on the knowledge found during this project and from other parts of the market, DOVISTA has initiated a further investigation and development of products and technologies supporting controlled ventilative cooling.

Since the development of the new control strategy for ventilative cooling in this project knowledge has been transferred to other projects:

- The developed integrated control strategy has been implemented in the control strategy for a new prototype roof window with integrated solar shading and ventilation developed by VELUX in the EUDP project ”Det bæredygtige ovenlysvindue (J.nr. 64015-0020)”.
- The developed integrated control strategy has been implemented in the EUDP project ”Bolig 2020 med lavt energiforbrug og høj brugerkomfort (J.nr. 64015-0640)”, by Schneider Electric

Knowledge will also be transferred to house builders as a Danish guideline for ventilative cooling targeting house builders is to be published as well as it has been integrated as part of the teaching activity at Aalborg University.

1.7 Project conclusion and perspective

The project has documented that overheating risk and cooling need at room level will appear in renovations, especially when energy performance levels after renovations is approaching requirements for new buildings. It has also documented that existing ventilation systems with a limited air flow capacity (often corresponding to an ACR of n=0,5 h^{-1}) cannot provide satisfactory cooling capacity, even if it is supplemented with short time manual window opening. Ventilative cooling is required during both day and night time to ensure comfortable conditions and automatic control is recommendable.

Based on the outcome of the project design guidelines for ventilative cooling has been developed and a design guide for Danish house builders and homeowners will be published that emphasizes the importance of considering ventilative cooling in renovation and provide guidelines for suitable solutions. European Standards and national Compliance tools (eg Be 18) will benefit from taking further into account ventilative cooling and the project participants will continue to stimulate this development to ensure the relevance of the technology also in legislative framework. It is the hope that in the future this will increase the awareness of the challenges and solutions - and lead to improved thermal comfort in deep renovations and in new buildings as well – without additional energy consumption.

Annex

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Psomas, T., Heiselberg, P., Lyhme, T., Duer, K. Automated window systems to address overheating risk on deep renovated dwellings. In proceedings of the 38th AIVC – 6th TightVent – 4th venticool conference, Nottingham, UK. September 2017.

Theofanis Psomas, Per Heiselberg, Karsten Duer, Eirik Bjørn, Ventilative Cooling Control Strategies in Energy Renovated Dwellings: A Parametric Analysis. Submitted for publication in International Journal of Ventilation.

Links to publications can be found at the website of Aalborg University:

http://vbn.aau.dk/da/persons/theofanis-ch-psomas(70754077-11fa-4f9f-93a1-558d01e1a65d)/publications.html