Efficient passive cooling of residential buildings in warm climates

T.F. Asmussen and P. Foldbjerg
VELUX A/S, Denmark

ABSTRACT

The energy performance and thermal comfort of three passive cooling methods have been investigated for a typical building in four cities in warm climates and compared to mechanical cooling. The passive cooling methods where: Venting via windows, solar shading and night cooling via windows. Different control schemes where used: Manual operation and control, Automatic operation and manual control, and Automatic operation and control.

Results from dynamic thermal simulations show that the energy demand can be substantially reduced by using passive cooling methods compared to mechanical cooling without compromising the thermal environment. Close to 100% of the occupied hours where in the comfort range when using automatic operation and control. The primary energy demand of the buildings was reduced from 150-160 kWh/m² with mechanical cooling to 15-40 kWh/m² with passive methods.

Achieving the best thermal environment requires automatic operation and control of the cooling systems.

1 INTRODUCTION

With the introduction of the Energy Performance of Buildings Directive (EPBD), (European Commission, 2002), in 2002 the focus on energy has risen rapidly in the EU member countries, where buildings account for 40% of the total energy consumption, (Strom et al., 2006). With the introduction of a target of nearly-zero energy buildings (ZEB) by 2020 in the recast of the EPBD, (European Commission, 2010), the focus on energy efficiency is reinforced in combination with a holistic focus on all contributors to the energy demand.

With the concept of nearly-ZEB, focus on reduction of cooling demands will increase, not least in warm, southern European climates. Here the challenge is the summer situation, i.e. achieving thermal comfort with low or zero cooling demand. The directive encourages the use of passive cooling techniques to avoid the unnecessary use of energy to counter the increased use of mechanical cooling.

Designing residential buildings without mechanical cooling which provide acceptable thermal conditions can be challenging in warm climates. Solar shading and openable windows providing natural ventilation are often installed but often not used to the full potential. Typically, these are manually operated and controlled and not put in use until it is too late. Automatic operation and intelligent control of the systems can be used to improve both energy performance and thermal comfort.

A balanced approach is required to optimize energy performance while maintaining good thermal comfort. Currently, there are no or very few standard products available for residential buildings which uses sensors to control the indoor environment. This paper addresses different passive cooling techniques, control scenarios, and the consequences on energy demand and thermal comfort.

2 METHOD

Dynamic simulations were made for a house in four cities in warm climates with different passive cooling methods and different controls. A reference case with mechanical cooling was also made for comparison. The simulations were made with the IDA ICE simulation tool, (EQUA Simulations AB, 2010).

2.1 House description

The house is based on (Kragh et al., 2008) and is a 1½ storey building of 175 m² internal floor area with a footprint of 8 x 12 m and a roof pitch of 45°, see Figure 1 for a visual representation. The construction properties are shown in Table 1. The leakiness is assumed to be 2 /h at 50 Pa. There is a window to floor area ratio of 20%. All windows are low energy windows with a U-value of 1.4 W/m²K (90°) and a g-value of 0.60.

Table 1: Thermal properties of the building envelope.

Construction	U-value [W/m²K]
Floor	0.2
Walls	1.2
Roof	0.8

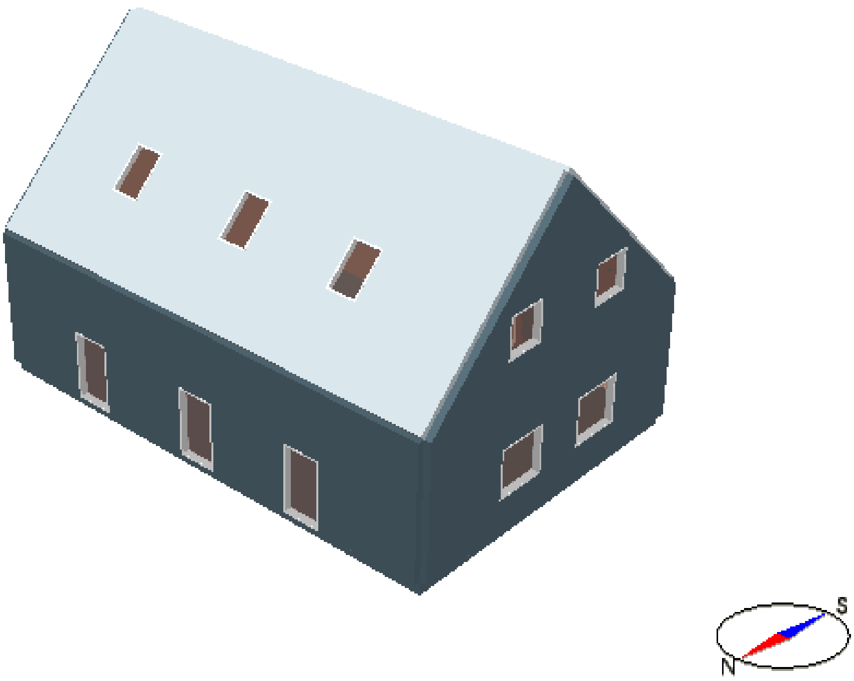

Figure 1: Visual representation of the simulated building.

2.2 Climates

The analyses have been performed for four locations in southern Europe, see Table 2 X.

Table 2: List of simulated locations.

#	City	Country
1	Athens	Greece
2	Istanbul	Turkey
3	Malaga	Spain
4	Palermo	Italy

2.3 Cooling methods

Three types of passive cooling are tested: Venting via windows, solar shading and night cooling via windows. Venting is only used when the occupants are at home and not at sleep. Solar shading is used depending on the control type, see Section 2.3.1. Night cooling is used when the occupants are at sleep. The control is designed to simulate the real life use: the occupants check the temperature before going to sleep. If the indoor temperature is too high and the outdoor temperature is lower than the indoor the window is opened and left open for the rest of the sleeping period. A matrix of the used cooling methods and cases are shown in Table 3.

Table 3: Case overview of the simulations.

	Cooling measures			
Name	Natural ventilation	Solar shading	Night cooling	Mechanical cooling
Mechanical cooling				X
Manual NV	X			
Semi manual NV	X			
Auto NV	X			
Manual NV + SH	X	X		
Semi manual NV + SH	X	X		
Auto NV + SH	X	X		
Manual NV + NC	X		X	
Semi NV + NC	X		X	
Auto NV + NC	X		X	
Manual NV + SH + NC	X	X	X	
Semi manual NV + SH + NC	X	X	X	
Auto NV + SH + NC	X	X	X	

2.3.1 Controls

The controls are divided into three types: manual, semi-automatic and fully automatic. The manual control is based on a manual use where the measures are not used until the occupants experience overheating. Furthermore, only a limited number of devices are used to simulate that an occupant would not use all windows in the house but only the ones close to their location in the house. The semi-automatic control is based on a manual control with a remote control to control the use of the windows and shadings. This means that the set point will still be when the temperature reaches discomfort but all relevant windows and shadings will be used. The last control is the fully automatic control that simulates a sensor based control that kicks in before overheating is reached. The set points and number of windows are shown in Table 4.

Table 4: Set points of the different system controls.

System	Set point temperature	Used windows
Manual	29°C	25%
Semi-automatic	29°C	100%
Fully automatic	25°C	100%

2.4 Evaluation method

The main purpose of a cooling system is to maintain a comfortable thermal environment. To evaluate thermal comfort the adaptive method of free running buildings from (CEN, 2007) is used. The passive cooled cases are considered free running buildings with comfort ranges as a function of the running mean temperature of the outdoor air temperature. The mechanically cooled case uses the fixed comfort range. The energy is converted to primary energy with a conversion factor of 2.5 for all locations. To weigh the thermal comfort and the primary energy a Cody-chart is used, (Cody, 2007).

3 RESULTS

3.1 Energy demand

For each location and case the primary energy demand was calculated. The electricity was converted into primary energy with a factor of 2.5 for all locations. The annual primary energy demand per square meter is shown in Figure 2.

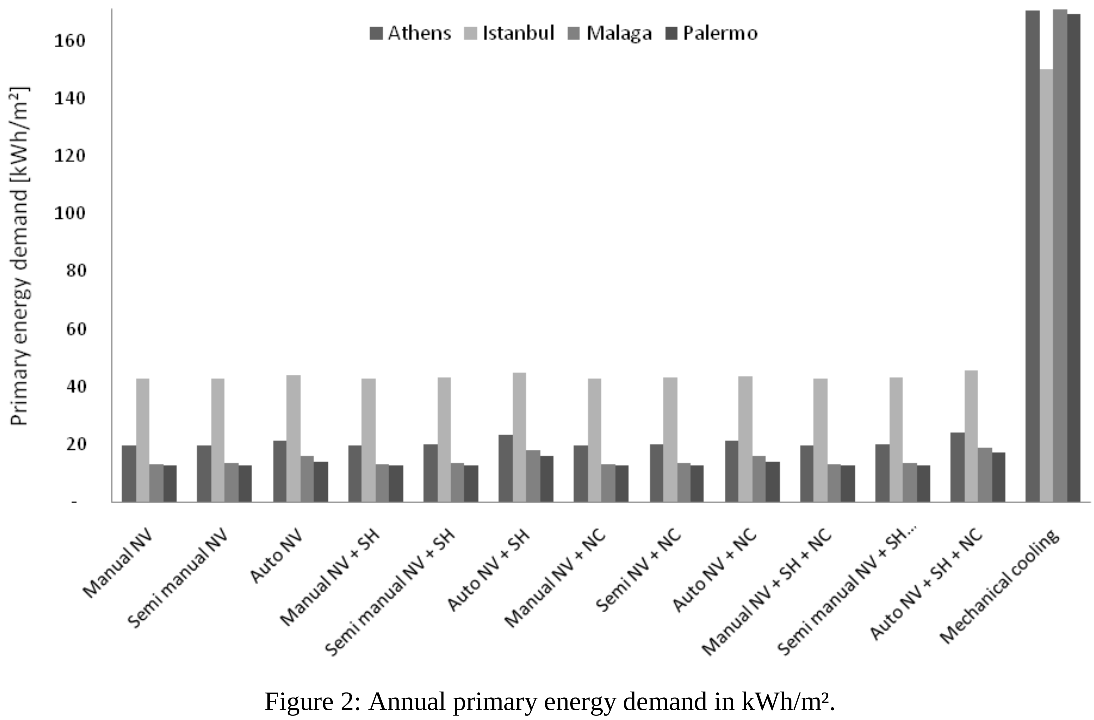

Figure 2: Annual primary energy demand in kWh/m².

From Figure 2 it is clear that the primary energy demand for the passive cooled buildings are substantially lower than the mechanical cooled case. Results from Istanbul are twice as high as the rest of the cases for the passive cooled cases. However, the cooling demand is lower than the other locations.

3.2 *Thermal comfort*

The part of the occupied hours with acceptable thermal comfort is shown in Figure 3.At night when the occupants are at sleep, discomfort due to low temperatures is not considered.

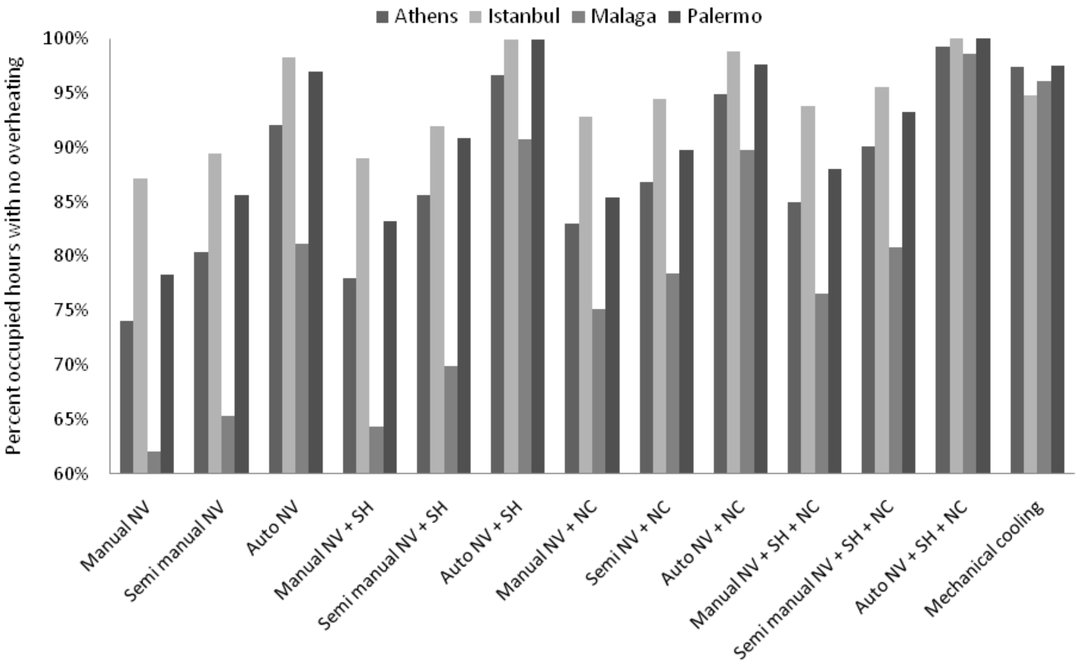

Figure 3: The part of the occupied hours with and without overheating.

The figure illustrates how the passive cooled case with automatic control delivers almost 100% accepted hours, which is a little higher than the mechanically cooled cases.

3.3 *Building energy and environmental performance*

Error! Reference source not found. shows a Cody-chart with the primary energy demand as the x-coordinate and the percentage unacceptable hours as the y-coordinate.

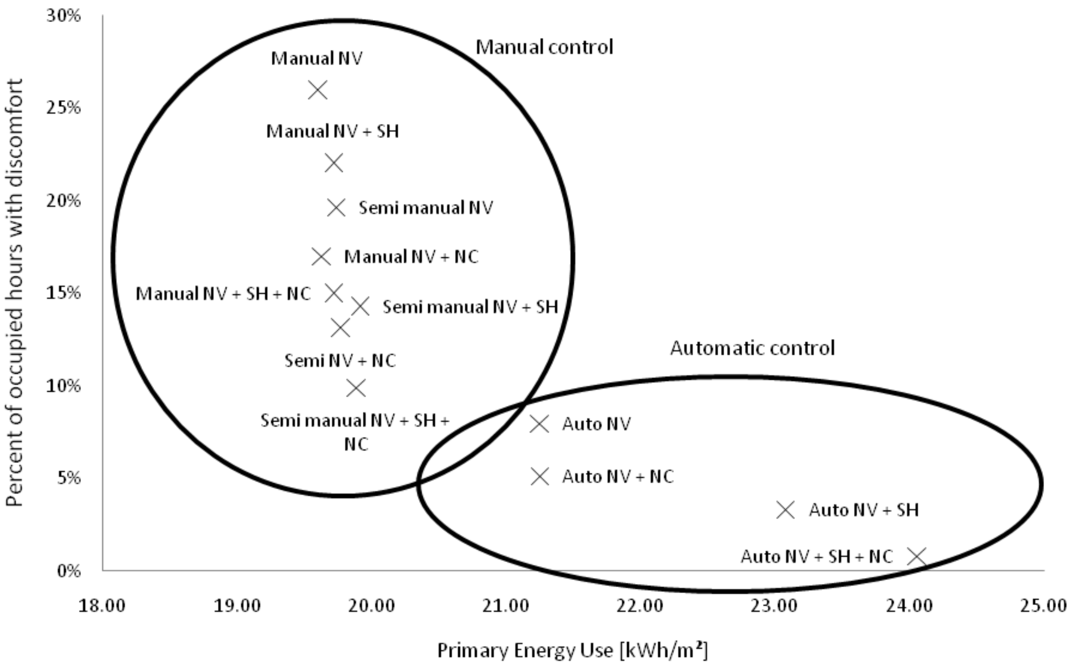

Figure 4 Cody-chart comparing the primary energy use and percent acceptable hours.

From the figure it is seen that the automatic controls has the lowest rate of discomfort but the highest primary energy demand.

4 DISCUSSION

The results show that mechanical cooling is not necessary to obtain acceptable thermal comfort. The combination of all three passive cooling methods (natural ventilation, solar shading and night cooling) with automatic control can deliver thermal comfort in the range of 98% to 99% of the occupied hours. The manual control has 62% to 92% occupied hours with comfort, and the semi automatic in the range of 65% to 95%. This is considered unacceptable. Hence, only the automatic controls are sufficiently efficient to maintain acceptable thermal comfort.

The automatic control has a higher primary energy demand than the manually controls. The reason for this is the transient periods between heating season and cooling season. At daytime cooling is needed to avoid overheating but at night the heating system is in use to maintain the heating set point. This is due to the chosen control methods which only focus on the indoor air temperature. More intelligent methods taking into account i.e. heating or solar radiation can optimize the use of the systems and lower the energy demand.

Still, substantial energy savings are achieved with the passive cooling methods, which perform a factor of 3 better than mechanical cooling for Istanbul which has the coldest climate. The other three locations have a factor between 7 and 10.

Automatic window venting has only been used when the occupants are at home. It can be a barrier to people to have a system open and close the windows when they are not at home. But by using a sensor based system the windows could open and close even when the occupants are not at home, which will maintain a good indoor environment when the occupants arrive at home.

The full combination of all the passive methods can deliver almost 100% acceptable hours at substantially lower primary energy consumption than mechanical cooling. This shows that with automatic control of passive cooling methods thermal comfort can be achieved close to 100% of the occupied hours with much less energy consumption than mechanical systems.

No such systems are available today as standard products. But electrically operated windows and automatic solar shadings products are available already, and the required knowledge and technology is available to create a control product which can achieve the best indoor environment with the least amount of energy used in warm climates.

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