Indoor comfort and energy savings by intelligent solar controlled windows in Southern Europe

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Abstract

On the basis of new and existing residential buildings around Europe, several simulation studies have been carried out by VELUX A/S and CSTB to show the effect of passive cooling systems for reducing cooling demand and optimizing the indoor climate by use of intelligent roof windows systems. The studies were made for typical existing and low energy residential buildings at several locations in France, Spain, Italy and Germany.

In this paper, only the results from the latest study which concerns Germany and France will be presented. The technology studied is an "intelligent" roof window which optimizes the use of passive solar gain, daylight availability and natural ventilation to keep a good indoor climate, while reducing the need for cooling and heating. The system activates a standard shutter/solar shading when needed, thus reducing the heating and cooling requirement while optimizing the daylight conditions. During the cooling season, when there is a risk for overheating, the intelligent and passive window system will activate natural ventilation through the windows and the shutter/solar shading, thus optimizing the indoor climate while reducing the requirement for cooling. During the heating season, the shutter/solar shading will be activated and act as an insulating shutter during the night, to reduce heat loss and thereby reducing the heating demand.

The findings from this and previous studies (Philipson et al, 2009) shows that in both new low energy housing and existing residential buildings in Southern and Central Europe, the use of energy for heating and cooling will be reduced by installation of roof windows with the use of "passive" strategies and technologies. Furthermore, the studies show an improved indoor climate in the building, where the indoor temperature can be kept at a lower level after the use of the technology without increasing the need for cooling, as well as improved daylight conditions in the building.

The intelligence lies in optimizing the use of the passive elements to reduce the need for heating and cooling while optimizing the indoor climate, before the active HVAC systems are activated and at the same time keeps it logical for the user. This is done automatically without feedback or control from the user. It is very important that the user finds these passive elements logical, otherwise the intelligent control will be overruled thus minimizing the possibilities for reduction in energy demand and optimizing the indoor climate.

Based on this work, an intelligent solar shading product has been developed by the VELUX Group. The product is presented as VELUX ACTIVE and awarded at BATIMAT in 2009 showing that this is not just theory – it can actually be done in practice. During the last year the product has been on the market with good results. However, VELUX are still improving the product based on the experiences from the markets.

Introduction

Correct use of a shutter/solar shading means in this manner, that it is activated during the night in the heating season and during the day when there is a risk for overheating. When controlled manually, shutters/solar shading are normally not activated all the times when it is needed, e.g. forget to pull it

Figure 1: Basic principle of the intelligent sunscreening "VELUX ACTIVE" developed by VELUX A/S.

Figure 2: Basic product functionally of the intelligent roof window.

down in the morning before leaving for work to avoid the risk of overheating when one returns from work.

An intensive study made by CSTB shows that by using manual control of shutters or solar shading devices, one can expect that only 70 % are used correctly during the heating season and only 50 % are used correctly during the summer/cooling season. Thus manual control of shutters and solar shading devices are not used as intended, which results in unnecessary increased energy use for heating, cooling and poor indoor climatic conditions.

Therefore, in spring 2008, VELUX A/S initiated a project together with CSTB for investigating which influence intelligent roof windows would have on new low energy housing and existing residential buildings in Italy and Spain. The aim of that study was to investigate the impact of intelligent passive roof windows on indoor thermal comfort, daylight availability and the energy consumption in residential housing. This study was carried out for several cities around Southern Europe, e.g. Rome, Palermo in Italy and Madrid and Malaga in Spain were investigated. These cities were chosen as representative for Southern Europe based on the climatic conditions. In this preliminary investigation (Philipson et al, 2009), only the shutter/solar shading is assumed to be self controlled, not requiring the presence of and intervention by the occupants of the building. The cooling effect of natural ventilation through roof windows are only included when the house is occupied.

The project continued into 2010, where an improved and intelligent algorithm for optimizing the control of the automatic shutter/solar shading has been investigated for several locations in France and Germany (Couillaud et al, 2009). The results from this study are investigated in this paper.

Intelligent roof window

The intelligent roof window consists of an outdoor temperature sensor and an outdoor pyranometer for measuring the solar radiation on the window. When these two parameters are known, then the intelligent suncreening, based on an algorithm developed by VELUX A/S, will determine whether or not if makes sense with regards to the energy demand and thermal comfort, to activate the shutter/solar shading device.

The basic principles are seen in figure 1 & 2 while the control strategy can be seen in figure 3.

During the heating season, the algorithm uses the knowledge of solar radiation to determine whether or not it is night. If it is night, the algorithm uses the outdoor temperature to determine if it makes sense to activate the shutter/solar shading to reduce the heat loss through the windows.

During the summer, when there is a risk for overheating the algorithm uses the outdoor solar irradiation and the outdoor temperature as input parameters, to define if there is a risk for overheating, and will activate the external solar shading device accordingly. The indoor temperature is not taken into account, since independent active heating and cooling systems will make sure that overheating or to low indoor temperatures will not occur – thus the passive systems will never be activated, unless the end-user themselves turn off the active heating and cooling systems or adjust the set points for heating and cooling. The main goal with this VELUX ACTIVE product was to have a simple and passive but effective system for residential buildings, that end-user easy would be able to install and see/feel the positive effects from.

The best would be to have an integrated and intelligent system that would be able to control all active and passive systems in a building for optimizing the energy demands and indoor

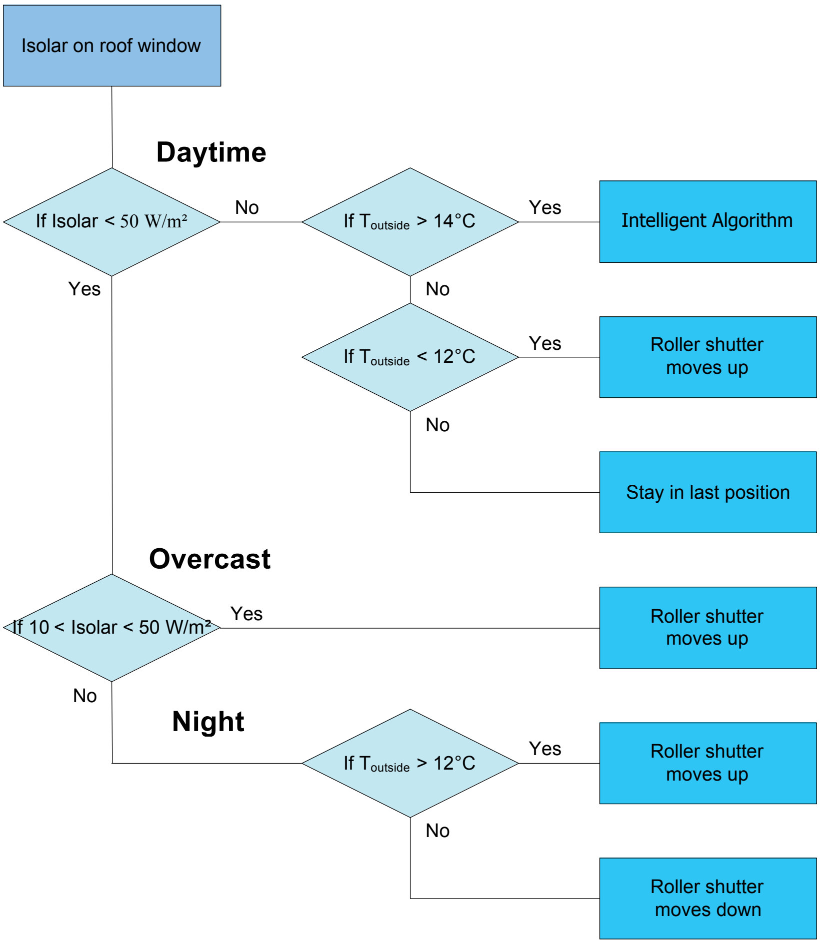

Figure 3: Schematics of the solar shading control by the intelligent roof window, with examples of set points.

climate. However, at this moment, these systems are still too far away to be realized into an actual product for use in residential buildings.

Control strategies

The intelligent roof window was simulated with two independent control schematics, one for natural ventilation and one for the intelligent suncreening/insulating shutter. The control for the intelligent suncreening is shown in figure 3, while in figure 4, the control strategy for the natural ventilation is shown.

Based on the inputs from the sensor for outdoor solar radiation the system determines if it is day or night, e.g. daytime representing risk of overheating, while nighttime represents risk of heat loss.

If it is daytime, the system determines the risk of overheating based on knowledge of the outdoor temperature and the solar radiation on the window. If it is nighttime, then based on the outdoor temperature, the system determines if it makes sense to active the shutter/solar shading device for reducing heat loss through the window. The choice of the numerical values has, been determined during several investigations by VELUX and is found to be an optimum between keeping operations at a minimum for the convenience of the end-user while keeping the energy demand for heating and cooling at a minimum.

The control strategy for the natural ventilation through the windows is shown below. There are 2 scenarios, one is in daytime and the other is at night. During the day, activation of natural ventilation is started if the indoor temperature exceeds 22 ˚C and at the same time exceeds the outdoor temperature. The 22 ˚C is chosen to make sure that the passive systems are activated before any active systems might be. Furthermore, the outdoor temperature should be above 14 ˚C to make sure that the risk of draught is kept at a minimum.

During the night scenario, the strategy is more or less the same, however a lower indoor temperature can be accepted, e.g. set point at 20 ˚C.

Simulation study

Since the simulations studies were carried out during several years and by different simulations experts in different parts of Europe, several different simulation tools were used.

The preliminary simulations by VELUX A/S were made with the Danish, dynamic simulation tool "BSIM" (www.sbi.dk). BSIM is used for simulating the thermal indoor comfort conditions and energy requirement in buildings, by using the ASHRAE weather data set with values for each hour. It is an integrated PC tool for analyzing buildings and installations. It includes a collection of advanced tools for simulating and calculating, for example, thermal indoor climate, energy consumption, daylight conditions, coupled simulation of moisture and energy transport in constructions and spaces, calculation of natural ventilation, and electrical yield from building inte-

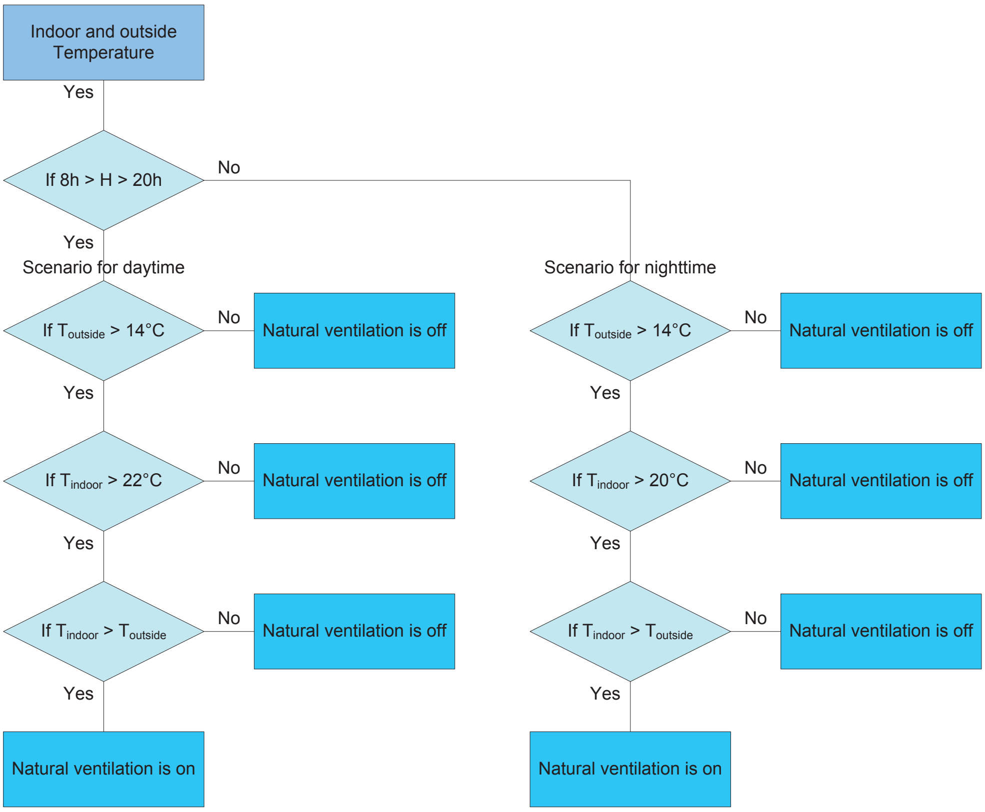

Figure 4: Schematics of the natural ventilation control by the intelligent roof window.

grated photovoltaic systems. It is used for planning, designing or analyzing energy consumption and indoor climate in connection with the design for almost any type of building. With BSIM2002 it is possible to perform all simulations and calculations based on one single building model. The building model is created as a complete 3D representation in the common graphical user interface and model editor for the whole program package. The model geometry can also be established by extracting the geometry from CAD drawings saved in DXF format.

The more detailed part of the analysis was made by VELUX A/S with the "IES VE", performance simulation software (www.iesve.com). In IES VE it is possible to build a 3D model with or without CAD. The core of VE is a powerful and flexible and most in-depth suite of building performance analysis tools. A variety of different interconnected modules are available so users can build the suite which meets their needs. Capabilities across energy/carbon, light/daylighting, solar, value/cost, CFD, and mechanical categories are covered. A central integrated data model allows analysis results and model data to be easily shared amongst applications for productivity gains, and to further inform and refine simulations. It contains information on geometry, materials, occupancy, climate and equipment.

CSTB in France used their simulation tool "SIMBAD" which contains a Building and HVAC Toolbox. SIMBAD is developed by CSTB in the Matlab-based Simulink environment. It can be used to design new control strategies for HVAC systems or local controllers. It is also used to build simulators for the evaluation of thermal comfort and energy consumption. These simulators can also act as emulators to test real controllers or energy management systems. The open structure of the models enables users to modify and personalize them. The product is used by manufacturers of control products for building systems, such as HVAC or lighting equipment, as well as research institutes and universities working in the field of building control and automation or energy management systems. The models are built hierarchically to make optimal use of the graphical environment. The multizone model allows the simulation of a complex building by dividing it in several zones that correspond to parts of the building. The model is constructed from basic models of building components: multilayer walls, windows, volume of air, radiation exchange by large and small wavelength. The model assumes that the building is simulated on a 'clear' site – i.e. the presence of surrounding buildings is not taken into account.

BUILDING TYPE

In the preliminary study, two different types of residential buildings were investigated. The first one represented new low energy housing, while the other one represented existing buildings. These buildings are seen as a compromise of the many different building types that are constructed in Spain and Italy.

During the latest study to see the influence of the intelligent roof window at room level, an attic room in a new residential building located in different cities in Germany and France were considered. An example of the room is visualized in figure 5.

The level of insulation, infiltration, etc. represents residential one family houses from the 1970 and 2008.

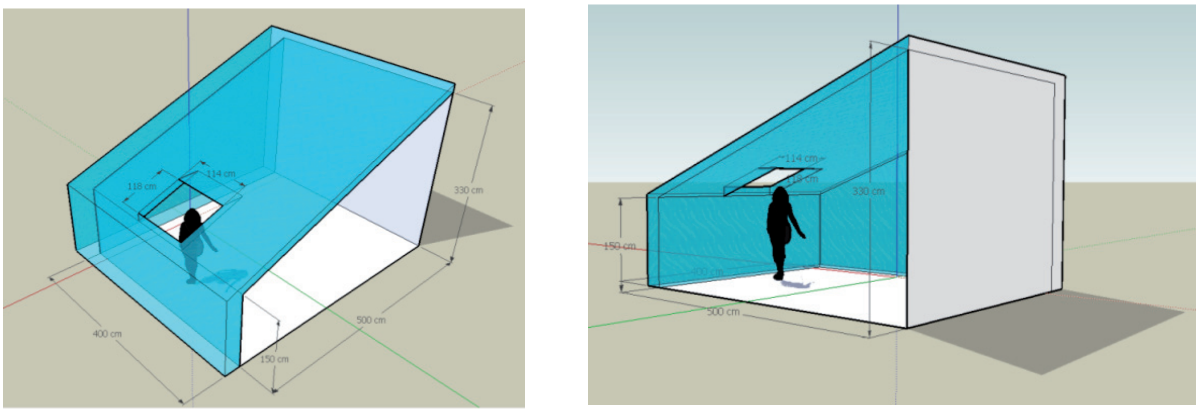

Figure 5: Attic room seen from the south east and from the north east. Only the façade and the roof are facing the outside. Building type used in new residential building in Germany and France.

Table 1: Thermal properties in the parametric study.

	Existing residential buildings	New residential buildings (room level)		Low energy residential buildings
Location	Spain	Germany	France	Italy
Climate	Madrid Malaga	Munich Hamburg Stuttgart	Paris Marseilles Lyon	Rome Palermo
Floor area	120 m^2	20 m^2	20 m^2	182 m^2
Window to floor ratio	15%	10%	10%	15%
U-facade [W/m^2K]	0,66	0,36	0,4	0,36
U-floor [W/m^2K]	0,49	n/a	n/a	0,32
U-roof [W/m^2K]	0,30	0,32	0,4	0,32
U_{facade}-windows [W/m^2K]	2,0	1,2	1,2	2,0
U_{roof} -windows [W/m^2K]	1,7	1,4	1,4	1,8

Results

The simulation studies were performed by VELUX A/S and CSTB independently of each other, based on the same set of assumptions. Good collaboration between VELUX A/S and CSTB has resulted in optimized control of the intelligent roof windows and findings that were concordant, even though two different simulation tools were used. In the following, only the results from the newest study (France, Germany) will be presented. The detailed results for Spain and Italy can be found in (Philipson et al, 2009)

EXPERIENCED TEMPERATURE IN FRONT OF THE WINDOW.

The experienced temperature is determined based on ISO 7730 which among others describes the thermal environment of the occupant. The method describes how the thermal comfort of a person in a room can be calculated based on knowledge of the person's activity level, clothing, the air temperature, the mean radiant temperature (surface temperature), the humidity level, the air velocity and the air temperature. The result of the calculation is a number – called PMV – ranging from negative numbers (cold) to positive numbers (hot). Zero is neutral and the optimal situation.

The experienced temperature is found for a person sitting or laying down in front of a window.

The PMV-number can also be converted to an "experienced temperature". For this purpose, the mean radiant temperature is considered to be equal to the air temperature. The assumptions for the occupant of the attic room is that it is an adult with an activity level of 1 met (sitting or laying down – representing indoor reading activity in residential buildings), wearing cloth as 0,9 clo (typical winter indoor clothing). The air velocity is 0,15 m/s, relative humidity level is 50 %.

The mean radiant temperature is taken from the output data from the simulations. Furthermore, the PMV level is adjusted with regards to the direct solar radiation, based on the method by Lyons and Huizenga (Window Performance for Human Thermal Comfort, ASHRAE Winter Meeting, Dallas, TX, February 5-9, 2000), where the PMV level is adjusted with 0,0024 PMV pr. W/m^2.

In figure 6 & 7, the experienced temperature for a warm summer day is shown for Marseille & Munich without mechanical cooling with and without the use of the intelligent suncreening. In all cases the natural ventilation strategy is the same.

From figure 6 and 7, it can be seen, that the use of a roof window with an intelligent suncreening, makes it possible to reduce the experienced temperature significantly with about 7 °C, even though we are located in Marseille. What is also seen is that the day starts with a high temperature, indicating that the day before also was hot since the days handled in this section represents a hot and sunny period.

This experienced temperature is not representing the air temperature inside the room/building but represents the experienced temperature for a person in front of the window. The operative temperature is also reduced significantly use of

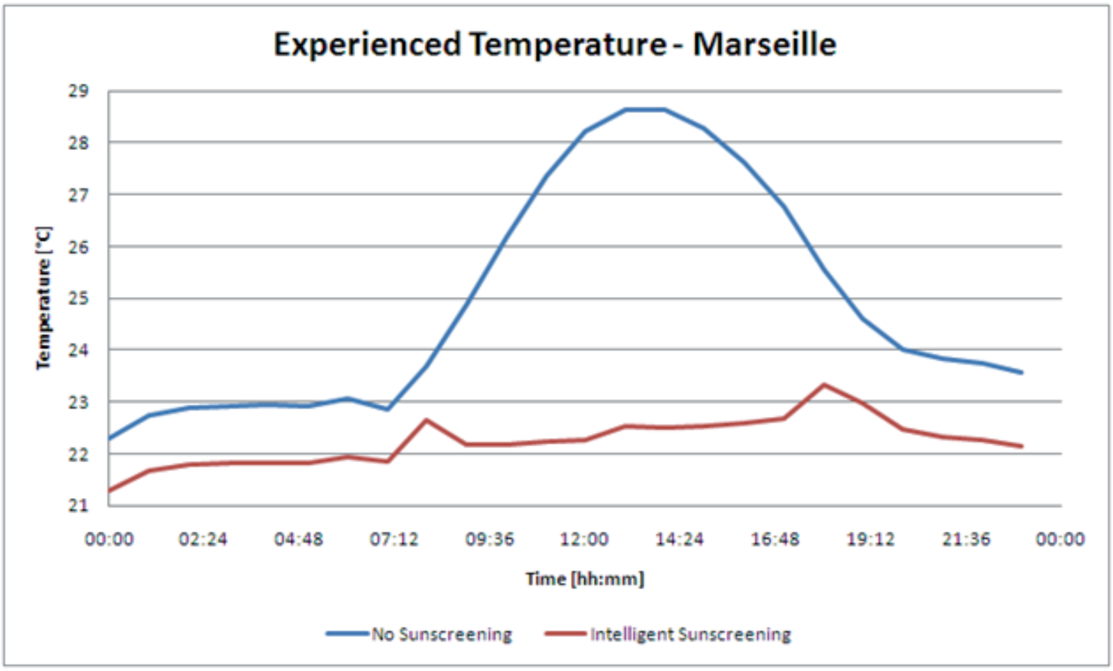

Figure 6: Experienced indoor temperature for Marseilles by use of intelligent sunscreening.

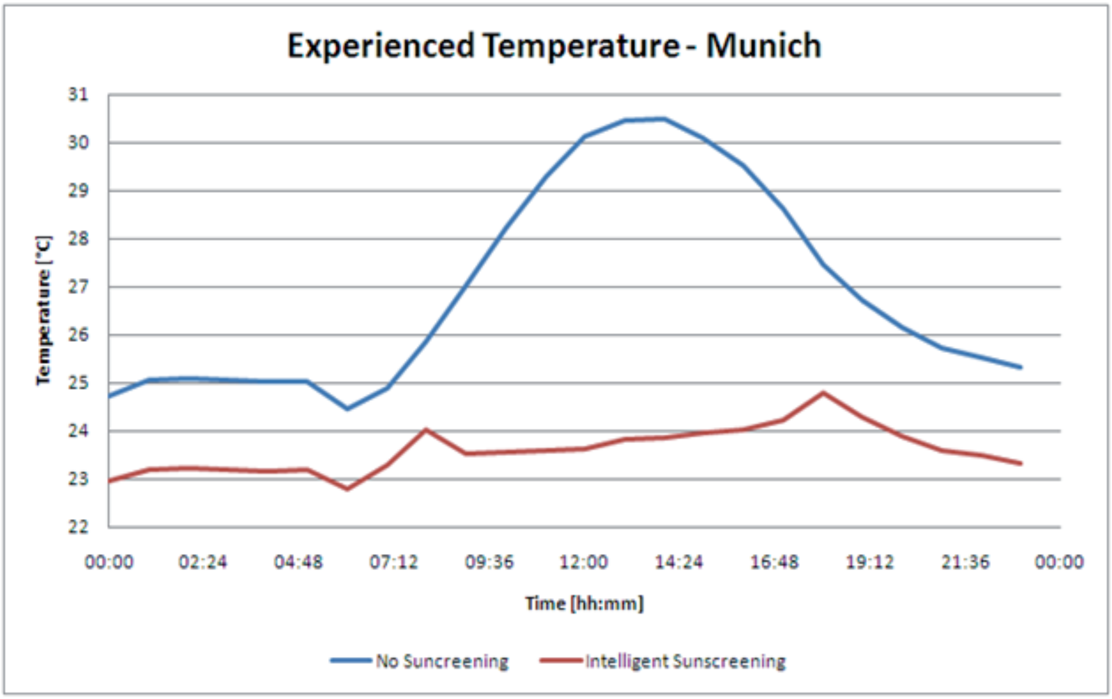

Figure 7: Experienced indoor temperature for Munich by use of intelligent sunscreening.

intelligent windows, however not as much as the experienced temperature in front of a window, this will be handled in the next section.

OPERATIVE TEMPERATURE

Instead of the experienced temperature, it might be more interesting to see the effect of the intelligent shutter/solar shading on the operative temperature in the room. This is illustrated in the figure 8 and 9, respectively for Munich and Marseilles, where the operative temperature is shown for the hottest day of the year.

From figure 8 and 9, it is seen that the operative temperature is reduced with about 4 ˚C, as compared to the 7 ˚C reduction in the experienced temperature. The 4 ˚C reduction is a significant amount of reduction and there is no doubt that the improvements in the indoor climate can be felt, whether or not one is in front of the window or not.

RISK OF OVERHEATING

The risk of overheating is expressed as the number of hours where the indoor temperature exceeds 25 ˚C.

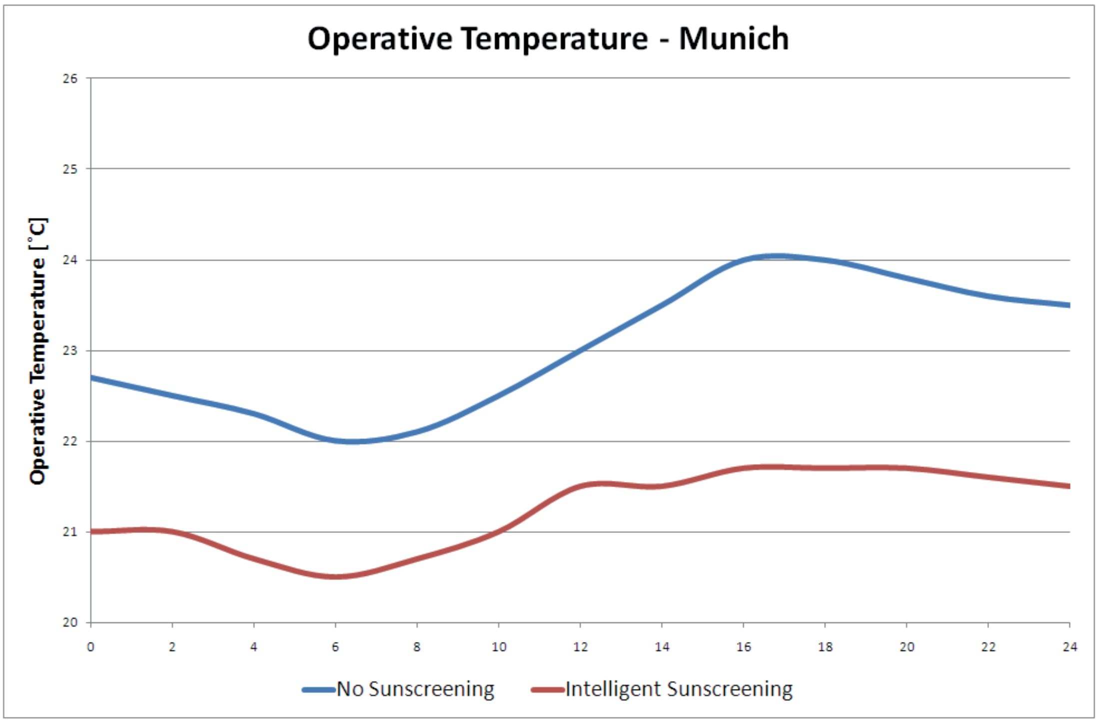

Figure 8: Operative temperature for Munich on the hottest day of the year, with and without intelligent sunscreening.

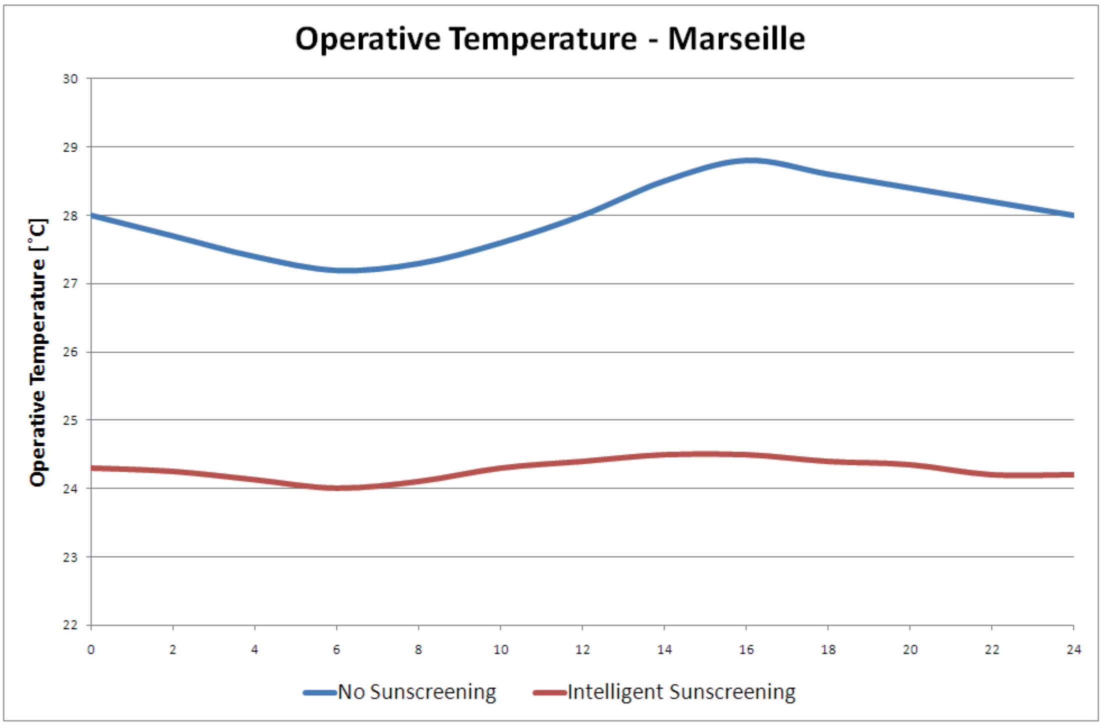

Figure 9: Operative temperature for Marseilles on the hottest day of the year, with and without intelligent sunscreening.

From figure 10 can be seen, that the risk of overheating is reduced by 30 %–80 % when an intelligent suncreening is used. The further south you go, the less the reduction of overheating in %, however in absolute numbers the reduction is quite significant.

Even for the Marseilles case, where the cooling demand and the risk for overheating is high, the reduction by using an intelligent suncreening is about 30 % (e.g. about 800 hours), thus a huge improvement. For the northern locations, the risk of overheating is eliminated.

ENERGY DEMANDS

The general tendency is that the energy demand for heating is reduced by about 2 % when the intelligent sunscreening is used. This is due to the intelligent control of the sunscreening, which during the heating season acts like an insulating shutter. It improves the U-value of the window by approximately 15 % at night when there is a heat loss, whilst it lets in the passive solar gain, when it can be used for passive heating of the building.

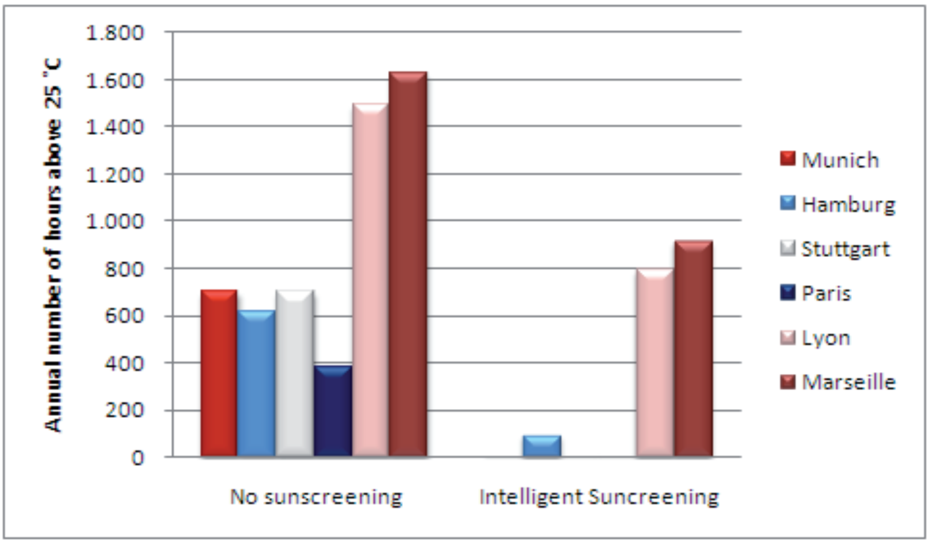

Figure 10: Number of hours where the indoor temperature exceeds 25 °C with and without intelligent suncreening.

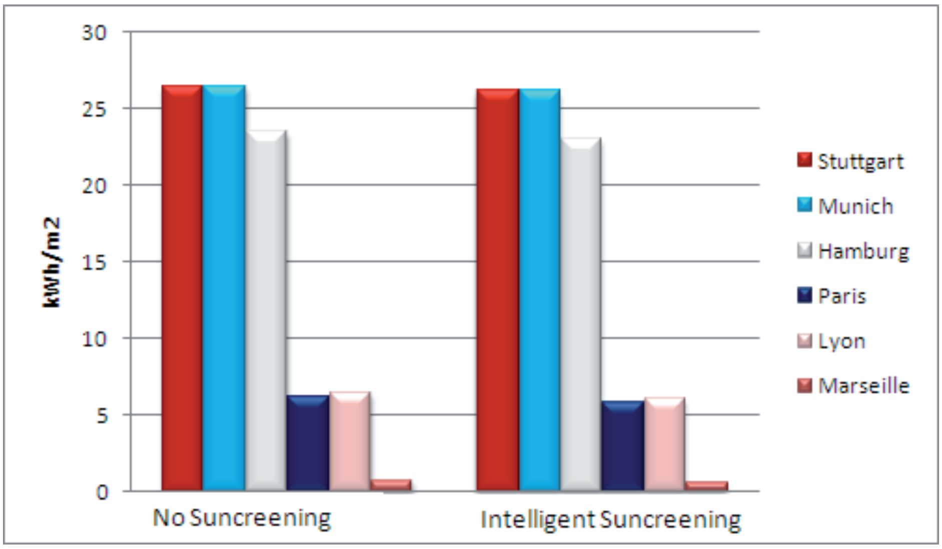

Figure 11: Energy demand for heating with and without intelligent suncreening.

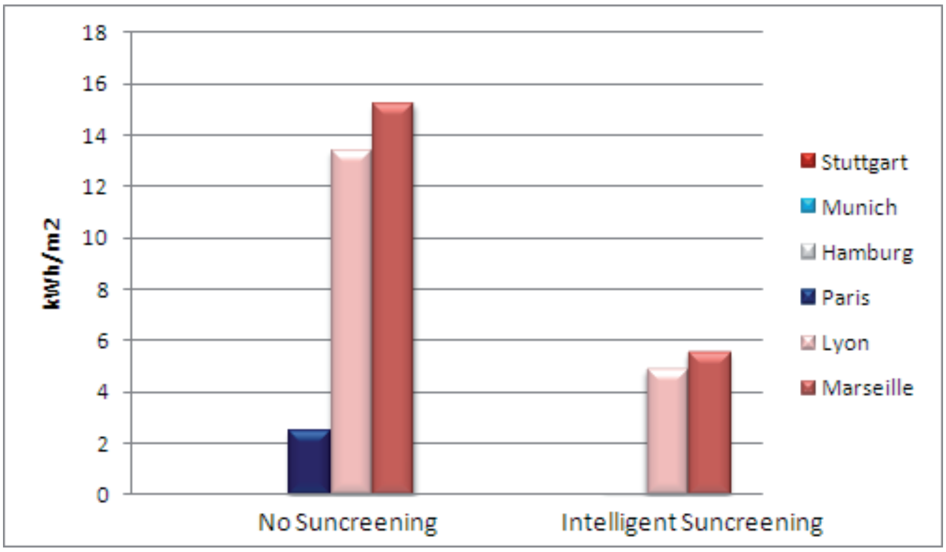

Figure 12: Energy demand for cooling with and without intelligent suncreening.

Further and great improvements can be achieved on the savings in energy demand for heating, if an insulating shutter was to be developed, which would improve the U value of window significantly more than the current 15 %.

Figure 11 shows that the energy demand for heating is slightly reduced for all cases. The colder the climate, the greater the reduction.

The energy demand for cooling is significantly reduced by use of intelligent solar shading. The energy demand for cooling is reduced by 70 % or more. If a manually solar shading device is used, about half of that reduction is estimated to be achieved.

The intelligent shutter/solar shading device is estimated to have around 1,000 operations during one year with a insignificant amount of energy needed for operation.

The energy demand for artificial lighting is increased a little, e.g. 1-2 kWh/m^2 with the use of shutter/solar shading device.

Conclusion

The findings show that in new residential buildings in France and Germany, the use of energy for heating and cooling will be reduced significantly by installation of active roof windows with the use of "active" strategies and technologies. In previous studies, (Philipson, et. al. 2009) it is shown that this also is the case for existing and low energy residential building in Southern Europe (Spain and Italy).

The studies also shows an improved indoor climate in the building, where the indoor temperature can be kept at a lower level after the use of the technology without increasing the need for cooling. The indoor thermal conditions have been evaluated from the PPD-PMV indicators described in ISO 7730.

By using an intelligent controller, the system provides a more balanced indoor climate and protects before overheating occurs. It automatically minimizes the risk of overheating by over 40 % and it lowers the experienced indoor temperature by up to 7 °C during hot summer days in front of the window, while the operative temperature is reduced with up to 4 °C. It reduces energy demand for cooling by over 50 % and reduces heat intake by up to 95 %, while the energy demand for heating is reduced.

The heating demand is approximately unchanged and it can be expected to be reduced further, the colder the climate. Furthermore, an insulation improvement of the shutter will lead to a further reduction in heating demand.

An intensive study made by CSTB shows that by using manual control of shutters or solar shading devices, one can expect that only 70 % are used correct during the heating season and only 50 % are used correct during the summer/cooling season. Thus a large part of the manually controlled shutters and solar shading devices are not used as intended, which results in unnecessary increased energy use for heating, cooling and poor indoor climatic conditions.

One of the advantages of product "intelligent suncreening" is that it continuously optimizes the indoor climate while reducing the need for cooling, even though the room/building is not occupied. This is a key factor for reducing the need for cooling and eliminating the risk of overheating, since the building is kept "cool" while the home is not occupied.

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