Energy and Buildings 135 (2017) 302–311

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The effect of dynamic solar shading on energy, daylighting and thermal comfort in a nearly zero-energy loft room in Rome and Copenhagen

Gunnlaug Cecilie Jensen Skarning*, Christian Anker Hviid, Svend Svendsen

Technical University of Denmark, Department of Civil Engineering, Brovej, Building 118, Kgs. Lyngby DK-2800, Denmark

ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
22 November 2016
Accepted 24 November 2016
Available online 27 November 2016

Keywords:
Dynamic solar shading
Solar-control coating
Roof windows
Window design
Residential buildings
Space heating
Climate-based daylighting
Adaptive thermal comfort

ABSTRACT

Dynamic solar shading is commonly suggested as a means of reducing the problem of overheating in well-insulated residential buildings, while at the same time letting daylight and solar irradiation in when needed. To critically investigate what dynamic shading can and cannot do compared to permanent alternatives in buildings with very low space-heating demand, this study mapped and compared energy, daylighting and thermal comfort for various combinations of window size and glazing properties, with and without dynamic shading. The study considered a loft room with sloped roof windows and moderate venting options in nearly zero-energy homes in Rome and Copenhagen. The more flexible solution space with dynamic shading made it possible to either reduce the time with operative temperatures exceeding the comfort limit by 40–50 h or increase daylighting by 750–1000 h more than could be achieved without shading. However, dynamic shading could not improve the optimum space-heating demand of the loft room in any predictable way, and without using dynamic shading, illuminances of 300 lx in 75% of the space could be achieved in 50–63% of the daylight hours with no more than 40–100 h exceeding the comfort ranges as defined by the Adaptive Thermal Comfort (ATC) model.

1. Introduction

As a result of ambitious energy strategies in the European Union, all new buildings are required to consume nearly zero energy by the end of 2020 [1]. This creates a strong need for research in cost-efficient window solutions and technologies that support very low energy consumption for space heating without compromising on daylighting and thermal comfort.

Several studies have identified overheating in the summer period and in the transitional seasons between winter and summer as a major problem in very well-insulated residential buildings in Europe, even in colder climates [2–5]. Dynamic solar shading is a commonly suggested means of reducing such problems of overheating, while still preserving a high access to daylight and solar irradiation through windows when needed [6–12]. In a house called ‘Home for life’ [6], which was designed and constructed in Denmark in accordance with the Active House specifications [13], dynamic shading combined with efficient venting strategies made it possible to achieve an average daylight factor of 5% without overheating, with overheating evaluated on the basis of the Adaptive Thermal Comfort (ATC) model [14]. Similarly, a systematic parameter study by Petersen [7] on window size, user patterns and cooling strategies in future homes based on the same daylight target doubts that it is even possible to achieve adequate daylighting in very low-energy buildings unless solar shading is applied to reduce overheating and thermal comfort is evaluated in accordance with the ATC model. Other studies on very well-insulated houses and nearly zero-energy homes, however, have questioned the importance of dynamic solar shading in buildings with a very low space-heating demand, due to the reduced need for solar gains in these buildings [2,15–18]. They suggest that solar control coated glazing with lower solar energy transmittances (g-values) and high selectivity for daylighting could be used to prevent overheating in such buildings, without critically affecting the space-heating demand. Such permanent glazing solutions are cheaper in comparison with dynamic shading and they do not face the same operational challenges or depend on successful control to perform well. On the other hand, dynamic shading options may be highly valued by users and designers who appreciate architectural freedom and user-flexibility in controlling the indoor environment. Currently, however, informed decisions on one or the other shading strategy tend to suffer from the lack of sufficient information about what can actually be achieved with

* Corresponding author.
E-mail addresses: gujs@byg.dtu.dk, gunnlaug_cecilie@yahoo.no (G.C.J. Skarning).

http://dx.doi.org/10.1016/j.enbuild.2016.11.053
0378-7788/

each of the shading strategies on energy, daylighting and thermal comfort all at once.

1.1. Aim of study

The aim of this study was to provide an example of what dynamic solar shading can and cannot do compared to solar control coated glazing in very well-insulated homes. Only effects of the shading strategies on transmittances of light and solar energy were considered. Potential effects on thermal transmittances [19,20] were not considered. The direct effects of dynamic solar shading would then typically be improved thermal comfort, slightly less daylighting and preferably no changes in space-heating demand at all. These effects can be determined in a relatively straight forward way by comparing the same window option with and without shading. In contrast, the full potential on energy, daylighting and thermal comfort of choosing one or the other shading strategy has to be derived from the flexibility found with each of the shading strategies before it can be compared. To be able to compare the full potential of the two shading strategies, we therefore first mapped the performance of various combinations of window size and glazing properties on energy, daylighting and thermal comfort, with and without the use of a supplementary dynamic shading device. Then, the best potential achievements on energy, daylighting and thermal comfort for the options with acceptable daylighting and thermal comfort were identified and compared.

This was done for a loft room with 45°-sloped roof windows, located in nearly zero-energy homes in Rome (Italy) and Copenhagen (Denmark). Loft rooms represent a situation with large risk of overheating and larger heat losses than in the rest of the building. On the other hand, sloped roof windows are known to provide twice as much daylighting as façade windows do [21].

To achieve a realistic picture of the energy, daylighting and thermal comfort potentials of the two shading strategies, the effect of the shading strategies on daylighting has to be taken into account in the analysis. Since this is only possible if daylighting is modelled dynamically throughout the year, the use of a climate-based approach for evaluation of daylighting (see Section 2.3.3) was central for carrying out this study, even though this is not yet common practice for housing.

1.2. Literature review

For office buildings, several studies have examined the thermal performance of dynamic solar shading along with effects on daylighting or electricity use for artificial lighting [22–40]. For residential buildings, studies by Mavrogianni et al. [8], Apte, Arasteh & Huang [9], Gugliermetti & Bisegna [10], Vanhoutteghem & Svendsen [15], Arasteh et al. [41], Firląg et al. [42], O'Brian, Athienitis & Kesik [43], Tsikaloudaki et al. [44], Kim et al. [45], Ali Ahmed [46], Karlsson, Karlsson & Roos [47] and Sullivan et al. [48] focused mainly on the thermal performance of solar shading. Considering the topic of dynamic roof windows, Klems [49] examined the summer performance of an electrochromic skylight through measurements in a test chamber, and amongst others concluded that better means of evaluating the benefits of daylighting would be needed to quantify realistically the performance of dynamic skylights compared to fixed-property skylights. Finally, not specifically focusing on roof windows, studies by Foldbjerg & Asmussen [6], Petersen [7], Du [50], Du, Hellström & Dubois [51], Yao & Zhu [52], DeForest et al. [53] and Carlucci et al. [54] considered both the thermal performance of solar shading and the effect of the shading on daylighting, visual comfort or electricity use for lighting in residential buildings. Since these studies assumed either fixed size or fixed properties of the glazing options compared, however, the full potential of using solar-control coating or dynamic shading was not transparently addressed. By exploring these potentials, the present study contributes to new knowledge within the field.

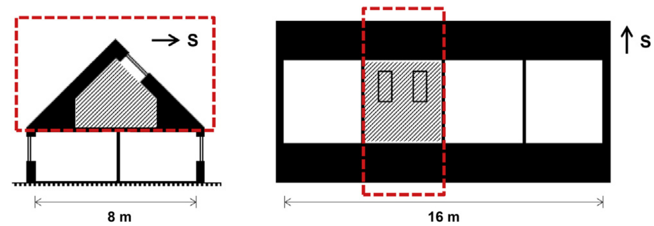

Fig. 1. Sketch indicating the location of the loft room in the middle part of a 1½-storey single-family house with simplistic floor plan: Vertical section of the house to the left and horizontal section of the 1st floor to the right.

Table 1
Building specifications for the thermal simulation model.

	Rome	Copenhagen
Roof construction		
U-value[a] (W/m^2 K)	0.15	0.08
Total thickness (mm)	300	550
Insulation thickness (mm)	150	400
Effective surface area exposed to the outside (m^2)	44.40	48.40
System properties and internal loads		
Heating set-point (°C)	20	20
Venting set-point (°C)	23	23
Infiltration rate (h^{-1})	0.05	0.05
Maximum rate for natural venting (h^{-1})	4	3
Mechanical ventilation rate (h^{-1})	0.6	0.6
Efficiency of heat recovery (–)	0.9	0.9
Loads from people, equipment and lighting (W/m^2)	5	5

[a] Includes linear heat losses.

2. Methodology

2.1. Loft room in a nearly zero-energy residential building

The study considered a loft room with floor dimensions of 4 × 4 m and ventilated room volume of 40 m^3, located in the middle part of the 1st floor of a 1½-storey single-family house (Fig. 1). This location represents the largest risk of overheating at the 1st floor. The loft room had single-sided daylighting access and natural venting options through two 45°-sloped roof windows in the south-facing roof surface. These were reasonable distributed on the width and positioned close to the top edge of the roof surface for optimal diffuse daylight access (see Fig. 1). The loft room was modelled as a separate zone with no air or heat exchange with other rooms in the building. No external obstructions were taken into account, and the surface reflectance was 70% for walls and ceilings and 30% for floors. The insulation of the roof and the settings for venting, infiltration and heat-recovery (Table 1) were selected to reflect the room's location in a single-family house that based on findings from previous studies [16–18] and test-simulations of different zones in the house was known to consume nearly zero-energy (as defined in Section 2.3.1). In general, the model assumed air-tight construction details of very high quality and mechanical ventilation with ambitious heat recovery efficiency to ensure acceptable fresh-air supply all year round with minimum heat losses. The use of the room is dwelling, as defined according to standard practice for documenting thermal comfort and energy consumption of residential buildings in Denmark [55]. This practice assumes a constant heat load per floor area from people and equipment in all rooms (Table 1), corresponding to an average size family with simplified user patterns living in an average size house.