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Optimized facade design - Energy efficiency, comfort and daylight in early design phase

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Abstract

Multi-functional and advanced building envelopes can provide step-change improvements in the energy efficiency and economic value of new and refurbished buildings, while improving the wellbeing of building occupants.
The scope of this work was to analyze the performance of different window configurations on indoor climate and to identify the most effective strategies for improvements.
This work investigated different strategies to improve thermal comfort in a case study by optimizing the responsiveness of the building skin by applying control strategies for cooling with natural ventilation and the use of automatically controlled shading devices.
This case study of a single-family house is located in the mountainous region of Norway. The results focus on summer temperatures and overheating, and daylight levels in the different rooms. Four rooms were found to be most critical for overheating during summer and the results confirm large number of hours with operative temperatures above 27°C in these zones. The results show that several rooms show high temperatures in summer, even with sun protection glass (type 2 and 3) and external screen (type 4 and 5). Cooling by natural ventilation by opening windows shows good results and proved to be effective in providing good summer comfort conditions. This has implications for the design and especially the choice of glazing and shading in residential buildings.

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1. Introduction

Multi-functional and advanced building envelopes can provide step-change improvements in the energy efficiency and economic value of new and refurbished buildings, while improving the wellbeing of building occupants. They therefore represent a significant and viable contribution to meeting the EU 2020 targets [1]. Advances in building performance design of nZEB, buildings that produce more energy than they use, clearly show the need for more focus on the building performance design which minimizes total energy needs in the operation of the building and with minimal material use.

In highly insulated and airtight residential buildings, a dedicated outdoor air ventilation system with a balanced mechanical ventilation system with heat recovery is used for providing air. The need for window ventilation is supposed to be substantially reduced or even eliminated [2; 3]. Changes in heating and ventilation strategy and require a thorough investigation and evaluation of the impact on the indoor climate, which comprises of the indoor air quality and thermal comfort. Recent studies found that there are higher temperatures in new residential buildings [3].

A central role can be dedicated to the building skin that needs to be to the highest degree responsive to their environment. This requires new approaches of adaptive building skins that instead of providing static performance parameter are able to adapt the physical properties and in that way optimize the overall performance of the building. One option for adaptation could be the use of automatically controlled shading devices that control heat fluxes through the window in dynamic way [4]. But also opening windows to allow for ventilative cooling can be considered a dynamic adaptive strategy [5; 6; 7]. Previously reported results confirm that shading of windows and opening windows can help to reduce discomfort during summer periods [11].

1.1. Objectives

The scope of this work was to analyze the performance of different window configurations on indoor climate and to identify the most effective strategies for improvements. The main focus was put on controlling solar shading and natural ventilation. For a single-family house, for different glazing types and different external screens operative temperatures and daylight levels needed to evaluated.

2. Methodology

This work investigated different strategies to improve thermal comfort in a newly designed single-family house by applying a responsive and adaptive building skin based on:

- Use of automatically controlled shading devices
- Applying control strategies for Natural ventilation

Daylight factors (DF) will not be affected as they are calculated for deactivated screens (overcast sky). It will however still reduce daylight availability in the zones since the screen is activated as a solar shading. The effect of daylight availability has been calculated. The hourly illuminance values for a 80 cm high working surface were plotted for each zone.

Table 1. Areas of building elements and their thermal properties.

Building element	Area, A [m^2]	Thermal transmittance, U [W/(m^2 K)]	Heat loss, U*A [W/K]	% of total
walls	299.56	0.13	39.63	27.04
roof	99.21	0.15	15.01	10.24
floor towards ground	87.17	0.07	6.16	4.20
floor towards outside	6.65	0.10	0.66	0.45
windows	63.04	0.83	52.54	35.85
doors	4.53	1.09	4.91	3.35
thermal bridges			27.64	18.86

Table 2. Glazing types used in the study.

type	SHGC (-)	Tvis (-)	$U_{glazing}$ W/(m² K)	Frame fraction (-)	U_{frame} W/(m2 K)	U_{win} W/(m2 K)	openable
1	0.423	0.314	0.703	0.1	2	0.833	No
2	0.302	0.215	0.702	0.1	2	0.832	No
3	0.302	0.215	0.702	0.1	2	0.832	Yes
4	0.041	0.014	0.626	0.1	2	0.825	No
5	0.041	0.014	0.626	0.1	2	0.825	Yes

Table 1 summarizes the amount and thermal properties building construction elements used in the case study. More than 35% of the heat losses through the building envelope is related to the windows.

Table 2 summarizes the glazing types used in the model. There are two different glazing types (type 1 and type 2) with different properties. The first glazing type has a three-layered glass with a U-value of 0.703 W/(m² K) with a frame with a U-value of 2 W/(m² K). The resulting U-value of the window with glazing type 1 is 0.833 W/(m² K). The second glazing type (type 2 and 3) has a solar screen integrated which reduces SHGC and visible transmission (T_{vis}). Note that type 2 is openable while type 3 is not openable. The opening is controlled by a PI controller that opens the windows when the room temperature is above 25 ˚C. In addition, there is an external screen as solar shading for type 4. The solar heat gain coefficient (SHGC) was calculated by combining glazing and screen properties [10].

The building case study consists of three storeys as illustrated in Figure 1. In the ground floor, there is the main entrance and a separate apartment (for rent). In the ground floor, there is in one part the main entrance, a storage, technical and a flexible use room. In the other part, there is a flat for rent with living room, sleeping and bathroom.

In the first floor, connected via a staircase, there are two training rooms, sleeping room, a hall and a bathroom (with adjacent washing room). In the second floor, again connected via staircase, there is one large room with living, kitchen and dining function (see Figure 2 for plans).

IDA ICE was used for this case study located in the mountainous region of Norway. IDA ICE has been validated using benchmark test [10]. The modelling environment allowed testing of window configurations during planning regarding visual and thermal aspects. Window ventilation was modelled in IDA ICE and is described in Bring et al. (1999) [9].

This case study is located in the mountainous region of Norway. The climate in this region north of Oslo is characterised by cold winters and cool summers. Figure 1 on the right shows the hourly temperature profile that illustrates the relatively low temperatures during summer with only few days reaching temperatures above 30°C.

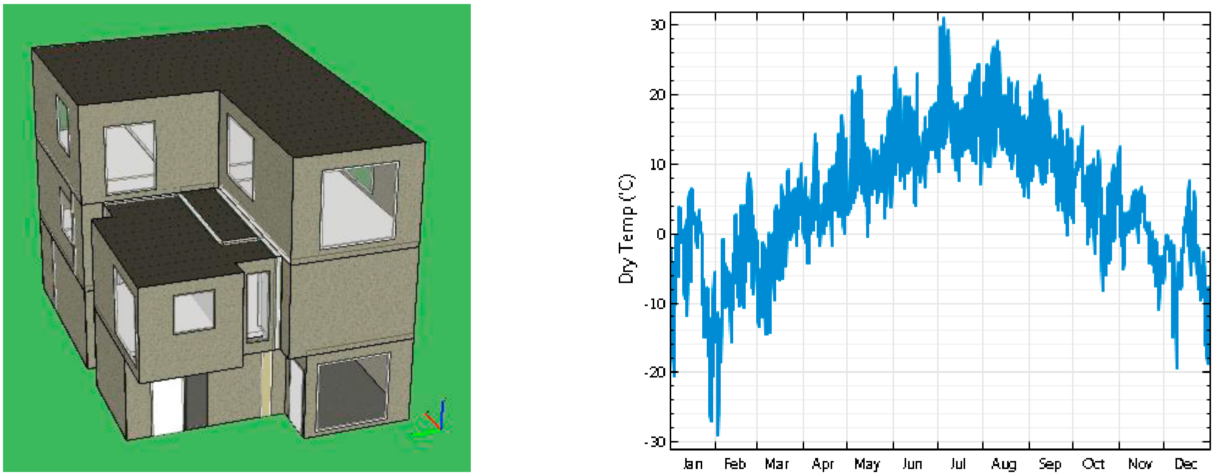

Fig. 1. left (a)sketch-up 3D model of the building; right (b) Dry bulb temperature for case study.

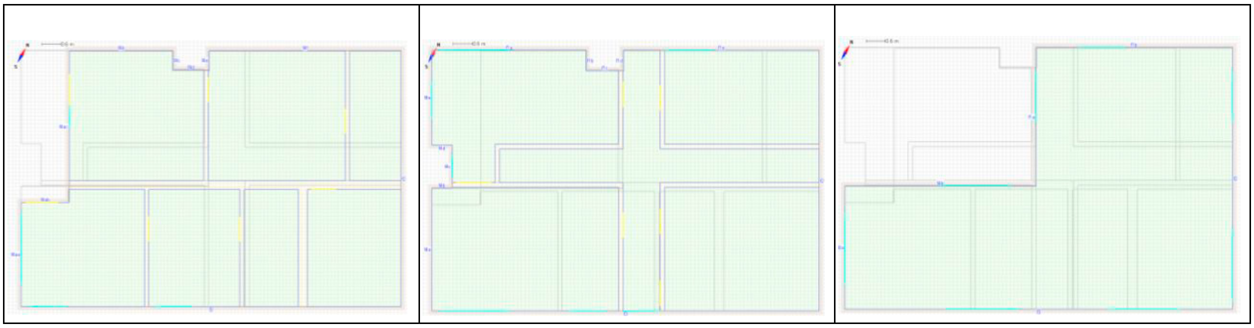

Fig. 2. Plans of the building with ground floor (left), first floor (centre) and second floor (right).

IDA ICE couples model to Radiance for daylight calculations. Hourly illuminance levels were calculated for each zone [10]. Thermal comfort was also studied (which depends on several parameters) but here only the operative temperature (T_op>27 ˚C) was used to indicate overheating in this study [10]. The heat gains from lighting, equipment and people were taken from NS3700, with 1.95 W/m2, 1.8 W/m^2 and 1.5 W/m^2 respectively. Heat gains from lighting and equipment were applied 16h per day from 06:00 to 22:00. The building is equipped with mechanical ventilation with heat recovery (η=80%), which is standard for Norwegian houses [12].

3. Results

Table 3 shows maximum operative temperatures for the different glazing types with and without external screen (see also type 4screen and type 3 in Table 2). Simulation results show that the 2nd floor is most prone to overheating (hours where the operative temperature T_op>27 ˚C). Without external shading there are 12 hours where operative temperature exceeds 27˚C. External shading reduces operating temperatures significantly. The amount of operative temperatures above 27˚C are observed in the Rental space (ground floor) with 3439 hours (T_op>27) for type 1 without screen which reduces to 2467 hours with type 2. Openable windows (type 3) reduces to 22 hours (T_op>27) and type 4 with screen to 90 hours and to 10 hours with screen and windows opening (type 5). This means that the external screen can reduce operative temperatures but openable windows are more effective in reducing overheating hours. The same effect can be observed in both training rooms (first floor) and in the living room (second floor).

Table 3. Overheating results for 5 types (according to Table 2).

Zone	floor	Tyoe 1 h of T_op>27, hours	Tyoe 2 h of T_op>27, hours	Tyoe 3 h of T_op>27, hours	Type 4 h of T_op>27, hours	Tyoe 5 h of T_op>27, hours
Rental space, living	ground	3439	2467	21.97	89.96	10.27
Rental space, sleep	ground	3250	2224	143.1	525.6	305.7
Rental space, bath	ground	2357	917.8	0	15.37	0
Entrance area	ground	1810	755.9	16.99	215.6	45.11
Storage room	ground	1922	782.2	0	20.14	0
Technical room	ground	1153	530.4	0	0	0
Flexible use	ground	1263	650.6	0	0	0
Training room 1	first	3492	2642	16.37	108.4	10.16
Sleeping room	first	2792	1649	42.81	156.6	11.02
Hall	first	3050	1925	46.36	303.2	58.42
Training room 2	first	2432	1411	21.96	283.9	22.78
Bathroom/washing	first	2868	1608	0	78.37	0
Living room 2. floor	second	3065	2174	13.69	258.2	11.08

Table 4. Daylight factors for types (according to Table 2).

Zone	Type 1 DF avg, %	Type 2 DF avg, %	Type 3 DF avg, %	Type 4 DF avg, %	Type 5 DF avg, %
Rental living room	4.789	4.074	4.074	3.992	3.992
Rental sleeping r.	1.652	1.38	1.38	1.359	1.359
Entrance	0.3533	0.3064	0.3064	0.3397	0.3397
Training room 1	2.662	2.142	2.142	2.126	2.126
Sleeping room	1.591	1.338	1.338	1.3	1.3
Hall	0.3933	0.3272	0.3272	0.3151	0.3151
training room 2	4.62	3.896	3.896	3.93	3.93
Living room 2. floor	6.416	5.33	5.33	5.21	5.21

Daylight factor results are shown in Table 4. It can be seen that average DF are above 2% for Rental space living room, Training rooms 1 and 2 and for the living room on the 2. Floor. DF are below 2% for the other zones. The highest DF is reported for the living room 2. Floor (DF = 5.21 %), rental space living room (3.992%) and the training room 2 (4.62% for type 1, 3.896% for type 2 and 3, and 3.93% for type 4 and 5). The results for hourly illuminance values for the four different zones (rental space, living, living 2. Floor and the 2 training rooms) are shown in in Figure 2. It illustrates the effect of the different glazing types (with and without screen) on daylight levels (see also Table 2). For glazing types 3 (y-axis) and 4 (x-axis) the effect can be seen e.g. in Figure 2 on the left; (a) for the living room 2. floor and (c) for the training room 1. Daylight levels are reduced to around 1000lux due to the effect of the screen. The effect is not so prominent for the zones on the right, Figure 2 (b) Rental space, living and (d) Training room 2.

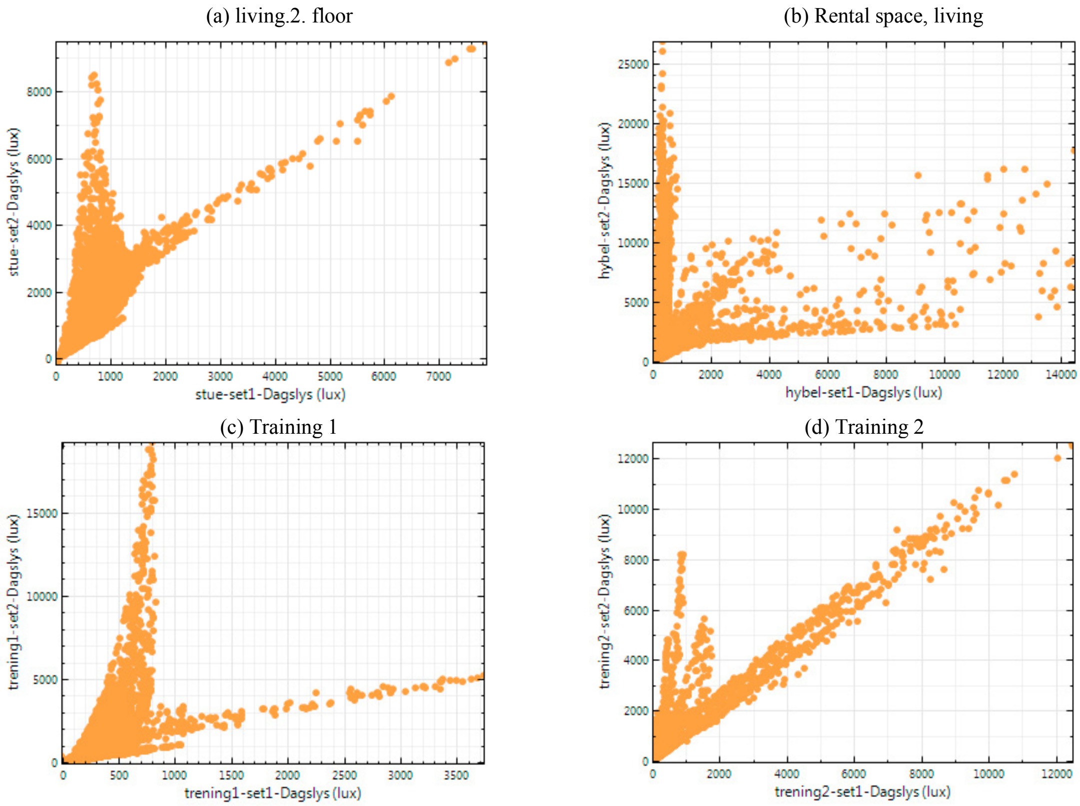

Fig. 2. Effect of external screen on daylight (a).

4. Conclusions

For a single-family house, operative temperatures and daylight levels were evaluated.

The results focused on summer temperatures and overheating and daylight levels in the different rooms in the house. Four rooms were found to be most critical for discomfort during summer:

- the rental space, living room (ground floor),
- both training rooms (first floor) and
- the living room (second floor).

The results confirm large amounts of hours when operative temperatures exceed 27˚C in these zones. Two strategies of adaptive and responsive building skin were applied to reduce discomfort during summer period:

1. Shading of windows with external screen
2. Ventilative cooling by opening windows

The characteristic climate in in the mountainous region of Norway with cool summer temperatures provides good potential for cooling by opening windows during this period of the year.

Advanced building performance simulation which incorporates several simulation models (for thermal and lighting evaluation) helped to improve thermal comfort in the design phase of a new single-family house design.

- The calculations show that zones: ground, 1st and 2nd floor all show high temperatures in summer, even with sun protection glass (type 2 and 3) and external screen (type 4 and 5).
- Natural ventilation proves to be an effective measure to reduce high temperatures in summer and reduce overheating hours significantly.
- The calculations show that daylight levels in the various rooms of the house has adequate values both with and without solar protection glass, although average daylight factor DF are below 2% in some zones.
- Daylight illuminance reduces for windows with solar shading.
- Further studies and laboratory and on-site measurements are needed to take into account
    - e.g. detailed daylight distribution according to activities
    - local discomfort due to direct solar radiation
    - dynamic daylight availability like e.g. daylight autonomy
    - detailed airflow studies to detect local discomfort

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