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Energy Procedia 122 (2017) 241–246

Energy Procedia

www.elsevier.com/locate/procedia

CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland

Consequences of energy retrofitting for daylight availability in Norwegian apartments based on measurements and simulations

Nicola Lolli*, Matthias Haase

SINTEF Building and Infrastructure, Høgskoleringen 7b, Trondheim 7465, Norway

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Abstract

Substituting existing windows for highly insulated glazing systems in Norwegian residential buildings may have a strong impact during the winter season due to the reduction of daylight availability. This paper investigates the consequences on the energy demand for space heating and electricity use for lighting of substituting existing windows with new windows and adding insulation in three apartment buildings located in Trondheim, Norway. The buildings were respectively built before the 1900s, in the first decade of the 1900s, and in the 1960s. The initial U-value of the external facades ranges from 0.96 to 0.26 W/m^{2}K, and is lowered to 0.15 W/m^{2}K after the renovation process. The U-value of the existing windows ranges from 1.6 to 2.8 W/m^{2}K. The new windows have a U-value of 1.1 and 0.6 W/m^{2}K. Scenarios are modelled to simulate the use patterns of artificial lighting in the apartments, based on occupancy schedules and required illuminance thresholds.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale

Keywords: Daylight Autonomy; energy efficiency: windows; electricity use, lighting

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1. Introduction

Daylight and solar radiation have a well-known influence on human health, by regulating the circadian rhythm, mood and behavior, as well as synthesizing vitamin D. Disruptions of day/night cycles are associated with higher

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* Corresponding author. Tel.: +47 450 633 20.
E-mail address: nicola.lolli@sintef.no.

Peer-review under responsibility of the scientific committee of the CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale
10.1016/j.egypro.2017.07.462

incidence of cardiovascular diseases, psychological problems, depression, and reduction in cognitive functions [1-6]. In such a perspective, windows are the building's most complex physical interface, as they are required to both allow satisfactory daylight penetration and view to the outdoors, but also limit the thermal exchange between the indoor space and the outdoor environment. This aspect is particularly critical at high latitudes, such as in Trondheim, were the winter conditions require well insulated buildings and high daylight penetration. The relationship between the thermal insulation, the visible transmittance, and the solar energy transmittance of glazing, with either clear or low emissivity glass panes, can be described with an asymptotic curve [7-10]. In practice, improving the thermal insulation of a glazing system will automatically lower its visible transmittance, which in turn has a negative influence on daylight availability in northern climates and increases the use of electricity for indoor lighting [11-13].

1.1. Objective

The scope of this paper is to investigate the consequences on the energy demand for space heating and electricity use for indoor lighting when substituting existing windows (center-glass U-value 1.6 and 2.8 W/m^{2}K) for new better performing windows (center-glass U-value 1.1 and 0.6 W/m^{2}K) commonly used in the upgrading of Norwegian residential buildings.

2. Method

This work is based on the case studies of three apartments, which are described in Table 1. The types of buildings used for the analysis, represent the majority of existing residential constructions in Norway. In order to obtain an accurate daylight analysis in the three apartments, the reflectance of the internal surfaces and the furniture is measured using a Minolta LS-100 luminance meter. This is done by comparing the luminance values measured on the internal surfaces with those measured on a standard grey card with an 18% reflectance. The resulting reflectance is used to characterize the corresponding surface in the 3-D model built for the daylighting analysis, which is performed in Daysim [16]. The illuminance values are calculated on a grid of 0.43 m cell size, located at 0.80 m above the floor level of the apartments. The illuminance results are validated through on-site illuminance measurements, which are not reported in this paper due to space limitations. The occupancy schedules and the type of tasks performed by the building users are modelled according to three suggested minimum illuminance levels, as shown in Table 2. The occupancy time during which the daylight simulations are performed is between 7:30 am and 11:30 pm, of which a 60% occupancy schedule is used to represent an average behavior of residential users. The three lighting levels modelled (100 lux, 300 lux, and 500 lux) are chosen to reflect three possible user activities requiring specific minimum illuminance levels [14]. The combination of the above parameters yields the scenarios presented in Table 2, and for which the Daylight Autonomy (DA) is calculated. The DA is the percentage of occupied hours in a year during which a given minimum illuminance level is met by sole daylighting and is described as:

$$DA = \frac{\sum_i (wf_i \cdot t_i)}{\sum_i t_i} \in [0,1] \quad \text{with} \quad wf_i = \begin{cases} 1 \; if \; E_{daylight} \geq E_{limit} \\ 0 \; if \; E_{daylight} < E_{limit} \end{cases} \tag{1}$$

Where t_i is the occupied time; wf_i is a weighting factor depending on $E_{daylight}$ and E_{limit}, which are the horizontal illuminance on the measuring plane given by daylight only, and the limit value of illuminance [15]. The DA calculation is performed with Daysim. Electricity use for lighting is calculated for three types of luminaires: compact fluorescent, LED, and a combination of the two above. The additional electricity use for lighting is calculated in kWh/year for all the scenarios and the three types of luminaires as:

$$Var.el.light. = el.light._{new\ windows} - el.light._{existing\ windows} \tag{2}$$

Table 1. Description of the case buildings.

Case study	Year	Description/U-value/Avg. int. surface reflectance	Additional insulation thickness/lambda/wall U-value	Window type/year/window area to floor area	Window Orientation/U-value/g-value/T_v	Window frame type/U-value
Building 1	1960s.	36-cm-thick timber frame with 15 cm mineral wool insulation. 0.26 W/m^{2}K. 0.65.	100 mm. 0.027 W/m K. 0.15 W/m^{2}K.	4 mm clear – 12 mm air – 4 mm clear. Mid 1980s. 0.11.	Windows on S, E, and W facades. 2.8 W/m^{2}K. 0.78. 0.82.	Wood. 1.50 W/ m^{2}K
Building 2	Before 1900.	27-cm-thick wood log construction with 5 cm mineral wool insulation. 0.31 W/m^{2}K. 0.58.	130 mm. 0.027 W/m K. 0.15 W/m^{2}K	4 mm clear – 12 mm argon – 4 mm low-e. Year 2000. 0.17.	Windows on NW facade only. 1.6 W/m^{2}K. 0.74. 0.75.	Wood. 1.50 W/ m^{2}K
Building 3	Circa 1900.	46-cm-thick brick construction with 3 cm air gap. 0.96 W/m^{2}K. 0.58.	210 mm. 0.027 W/m K. 0.15 W/m^{2}K	4 mm clear – 12 mm air – 4 mm clear. Mid 1980s. 0.18.	Windows on NW facade only. 2.8 W/m^{2}K. 0.78. 0.82.	Wood. 1.50 W/ m^{2}K
All buildings (Window type 1)	-	-	-	4 mm clear – 16 mm argon – 4 mm low-e	1.1 W/m^{2}K. 0.63. 0.80.	Wood 0.65 W/ m^{2}K
All buildings (Window type 2)	-	-	-	4 mm low-e – 16 mm argon – 4 mm clear – 16 mm argon – 4 mm low-e	0.6 W/m^{2}K. 0.50. 0.71.	Wood 0.65 W/ m^{2}K

Table 2. Description of the scenarios used in the daylight analysis.

Scenario	Window type	Required minimum lux level	Notes
S. 1	Existing(a)	100	(a) Visible transmittance of window is 0.82 for Buildings 1 and 3, and 0.75 for Building 2.
S. 2	Existing(a)	300	
S. 3	Existing(a)	500	
S. 4	Window type 1(b)	100	(b) Visible transmittance of window is 0.80 for all buildings.
S. 5	Window type 1(b)	300	
S. 6	Window type 1(b)	500	(c) Visible transmittance of window is 0.71 for all buildings.
S. 7	Window type 2(c)	100	
S. 8	Window type 2(c)	300	
S. 9	Window type 2(c)	500	(c) Additional insulation
S. 10	Existing(d)	300	Occupancy is set to 60% of the occupied time for all scenarios.
S. 11	Window type 1(d)	300	
S. 12	Window type 2(d)	300	

The calculation of the energy use for space heating is carried out for the three apartments before and after the retrofitting actions. The specifics of the measures taken are shown in Table 1. The heating system is based on electric heaters with a 98% efficiency [17], which is typical in old apartments in Norway [18]. The operative temperature is 21 C for 16 hours a day, and 19 C for 8 hours a day [17]. The annual energy use is calculated using IDA ICE v.4.7 [19].

3. Results

The results of the DA calculations, according to Equation (1), are presented in box and whiskers charts showing the distribution of the values on the simulation grid. The demarcation line between the black and the white box gives the median value. The additional electricity use for indoor lighting, according to Equation (2) and the scenarios in Table 2, is symbolized as circles. The visible transmittance of the windows is henceforth abbreviated as V_t.

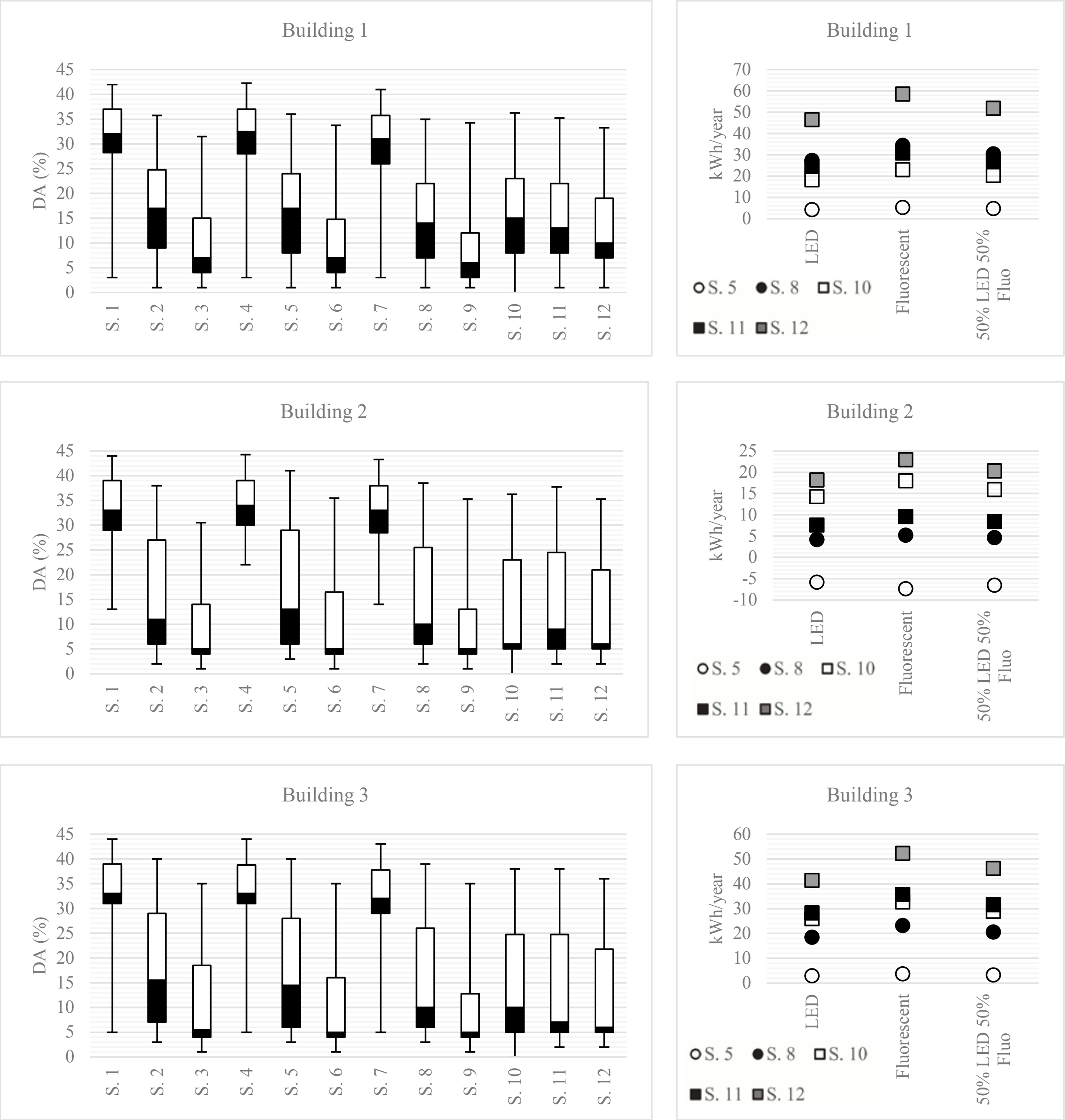

Fig. 1 (a) results of Daylight Autonomy for the three buildings; (b) additional electricity use for lighting in the three buildings calculated for a 300 lux level.

The calculation of the DA in Building 1, according to Eq. (1), shows that the median value of the DA is very similar for identical required lux levels, regardless of the type of windows used. This is shown in Fig. 1(a) by comparing scenarios S. 1, S. 4, and S. 7 (100 lux), S. 2, S. 5, and S. 8 (300 lux), and S. 3, S. 6, and S. 9 (500 lux). The only significant difference occurs between scenarios S. 2, S. 5 (which both give a DA with a 17% median) and S. 8 (which yields a DA with a 14% median). A similar trend is seen in both Building 2 and 3, where, as for Building 1, the only notable difference is seen between the 300 lux level scenarios. The use of the most insulated window (with a V_t of 0.71) decreases the median value of the DA by 20% in Building 1, and by 30% in Building 3 when DA is calculated for a 300 lux threshold. However, there is no significant difference of DA between scenarios S. 2 (existing window) and S. 8 (window with V_t 0.71) in Building 2, because the visible transmittance of the existing window is quite low (0.75, as shown in Table 1). For this reason, in Building 2, the use of the most insulated window does not significantly change the DA either, although it greatly increases the insulation level of the facade. In all buildings, the variation of the DA due to substituting windows when the required luminance is 100 and 500 lux, is always below 5% (Scenarios S. 1, S. 4, S. 7, and S. 3, S. 6, S. 9). The scenarios S. 10 through S. 12 suppose both substituting windows and adding extra insulation to lower the U value of the wall to 0.15 W/m^{2}K. The DA is only calculated for a 300 lux level in these scenarios. By comparing the results obtained for the same type of windows in Building 1 (S. 2 and S. 10 for the existing window, S. 5 and S. 11 for the window with Vt 0.80, and S. 8 and S. 12 for the window with V_t 0.71), the presence of additional insulation reduces the median value of the DA by 12% (existing window), 24% (window with V_t 0.80), and 28% (window with V_t 0.71). Similarly in Building 2, the DA median decreases by 45% (existing window), 30% (V_t 0.80), and 40% (V_t 0.71). Additionally, it should be noted that the median of the DA is below 10% in S. 10, S. 11, and S. 12 in Building 2, while it is between 10% and 15% in Building 1 (due to the different distribution of windows on the facade, as shown in Table 1). In Building 3, this comparison shows that the median of the DA decreases by 35% (existing window), 52% (V_t 0.80), and 40% (V_t 0.71). As in Building 2, the window distribution in Building 3 is on one side only, which gives a larger reduction of the DA than the one observed in Building 1.

Figure 1(b) shows the additional electricity need due to the substitution of windows, calculated according to Eq. (2). The results confirm the findings observed when calculating the variation of DA for the different scenarios. The additional insulation layer causes an increase of the electricity use for lighting, which is higher in Buildings 2 and 3 than in Building 1. This is shown by comparing the results obtained for scenario S. 5 (V_t 0.80), S. 8 (V_t 0.71), and S. 10 (V_t 0.80 + extra ins.). In Building 1, S. 10 requires less additional electricity use comparatively to S. 8, while the opposite occurs in Buildings 2 and 3. Given the NW orientation of Buildings 2 and 3, the additional insulation prevents morning sunrays to enter the building. On the other hand, the distribution of windows along three cardinal directions in Building 1 compensates for the loss of daylighting. Negative values yielded by scenario S. 5 in Building 2 are because the visible transmittance of the window type in this scenario is higher than that of the original window, leading to savings in connection to electricity use for artificial lighting.

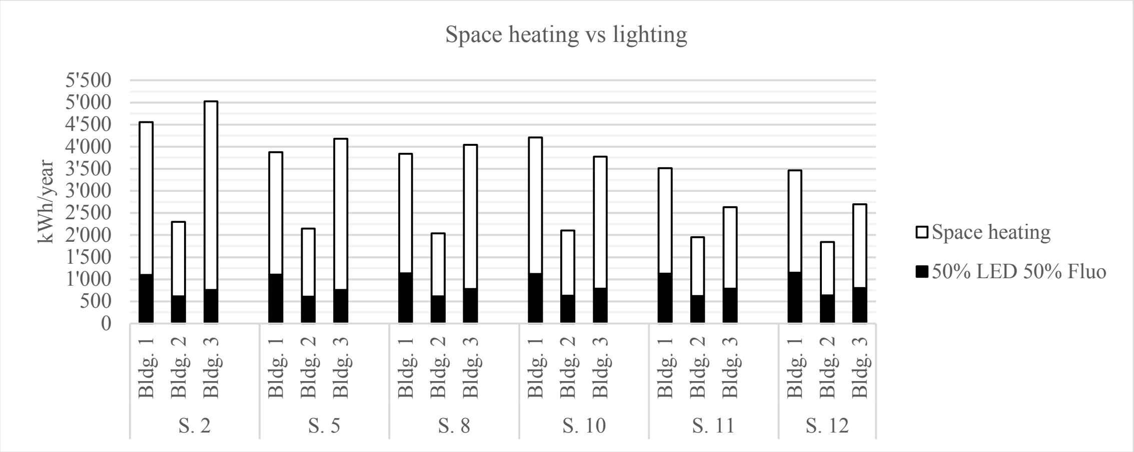

Fig. 2 comparison of electricity use for space heating and electricity use for lighting (50% LED and 50% compact fluorescent).

Figure 2 shows the comparison between the electricity use for space heating (98% efficiency electric heaters) and for lighting. The total electricity use is very similar in both S. 5 and S. 8 for all buildings. This is because the combination of a lower visible transmittance and a lower g-value for the window in S. 8 counter effects the energy savings otherwise provided by the better U-value. The addition of extra insulation alone (S. 10), gives a higher electricity use than when substituting windows (S. 5 and S. 8). The best performing scenarios are obtained by combining additional insulation and improved windows (S. 11 and S. 12). However, it should be pointed out that in the two last scenarios, the share of the electricity used for indoor lighting is approximately 1/3 of the total calculated electricity use (which does not include electricity use for appliances and domestic hot water).

4. Conclusions

Daylighting analysis carried out in three residential buildings in Trondheim before and after retrofitting windows, show that such measures lead to a significant reduction in daylight autonomy when the tasks performed require 300 lux or more. Furthermore, the addition of extra insulation on the facade, and the resulting increase in wall thickness, also notably influences DA values negatively. Overall, it was found that these common retrofitting efforts most critically affect buildings with NW-facing windows only. This finding is further supported by the results of the calculations of additional electricity demand for indoor lighting due to lower daylight availability. However, the comparison between electricity use for space heating and for indoor lighting shows that there is no significant difference between the use of double or triple glazed windows.

5. Acknowledgements

This paper is written within the SINTEF Building and Infrastructure institution, department of Architecture, Materials and Structures. The authors gratefully acknowledge the support from the Norwegian State Housing Bank.

References

[1] A.R. Webb, Considerations for lighting in the built environment: Non-visual effects of light, Energy and Buildings, 38 (7) (2006) 721-727.

[2] J.A. Veitch, Investigating and influencing how buildings affect health: Interdisciplinary endeavours, Canadian Psychology, 49 (4) (2008) 281-288.

[3] J.A. Veitch, Light, lighting, and health: Issues for consideration, Leukos, 2 (2) (2005) 85-96.

[4] L. Heschong, Daylighting and human performance, ASHRAE Journal, 44 (6) (2002).

[5] P.R. Boyce, Review: The Impact of Light in Buildings on Human Health, Indoor and Built Environment, 19 (1) (2010) 8-20.

[6] L. Edwards, P. Torcellini, A Literature Review of the Effects of Natural Light on Building Occupants, National Renewable Energy Laboratory, 2002.

[7] J.M. Schultz, K.I. Jensen, F.H. Kristiansen, Super insulating aerogel glazing, Solar Energy Materials and Solar Cells, 89 (2-3) (2005) 275-285.

[8] J.M. Schultz, K.I. Jensen, Evacuated aerogel glazings, Vacuum, 82 (7) (2008) 723-729.

[9] P.D. Robinson, M. G Hutchins, Advanced glazing technology for low energy buildings in the UK, Renewable Energy, 5 (1-4) (1994) 298-309.

[10] K.I. Jensen, J.M. Schultz, F.H. Kristiansen, Development of windows based on highly insulating aerogel glazings, Journal of Non-Crystalline Solids, 350 (0) (2004) 351-357.

[11] I. Richardson, M. Thomson, D. Infield, A. Delahunty, Domestic lighting: A high-resolution energy demand model, Energy and Buildings, 41 (7) (2009) 781-789.

[12] M. Krarti, P.M. Erickson, T.C. Hillman, A simplified method to estimate energy savings of artificial lighting use from daylighting, Building and Environment, 40 (6) (2005) 747-754.

[13] P. Ihm, A. Nemri, M. Krarti, Estimation of lighting energy savings from daylighting, Building and Environment, 44 (3) (2009) 509-514.

[14] S. Norge, NS-EN 12464-1:2011. Lys og Belysning. Belysning av arbeidsplasser., 2011.

[15] S. Carlucci, F. Causone, F. De Rosa, L. Pagliano, A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design, Renewable and Sustainable Energy Reviews, 47 (2015) 1016-1033.

[16] C. Reinhart, O. Walkenhorst, Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds, Energy and Buildings, 33 (7) (2001) 683–697.

[17] Standard Norge, NS 3031:2007, 2007.

[18] E. Arnstad, T.O. Askjer, R. Landet, T. Helle, T. Strandskog, Energieffektivisering av bygg: en ambisiøs og realistisk plan mot 2040, Kommunal- og regionaldepartementet, Oslo, 2010.

[19] IDA ICE, EQUA Simulation ABa, Solna, Sweden, 2016.