Implications of Increasing Daylighting in Deep Energy Retrofitting in Norwegian Shopping Centres

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Abstract

The analysis of 11 shopping centres in Europe reveals a lack of availability of indoor natural daylight, especially in shops and sales areas. The aim of this paper is to investigate the consequences on energy consumption and electricity use for lighting that novel retrofitting measures have when applied to Norwegian shopping centres (Haase et al., 2015a).

Internal daylight and internal illuminance levels were measured in two shopping centre buildings in Trondheim and Modena together with detailed monitoring of energy use and indoor air quality.

Scenarios were modelled to simulate the artificial lighting use patterns and control strategies in the shopping centres by considering occupancy hours and type of activity (illuminance levels), in order to cover different possible combinations used in the energy and daylight simulations.

Existing conditions of shopping centres (pre-retrofitting) in Trondheim, Norway were modelled based on drawings and validated with energy use measurements. Energy and daylighting simulations were performed and combinations of use pattern scenarios and facade variables were used to evaluate the influence on the electricity use for lighting and energy use for heating and cooling of the different scenario combinations. There is a trade-off, which is quantified in terms of reduction in electricity use and cooling demand as well as an increase in heating demand. The implications of lighting retrofitting on heating and cooling (aside from the end energy use savings) make the application complicated in shopping centres. Modelling and simulation of a shopping centre can help us understand the holistic consequences of single energy retrofitting measures.

1. Introduction

The paper is part of activities performed in the CommONEnergy project, where the aim is to transform shopping centres into lighthouses of energy efficiency. It is a project with 23 partners that studies comprehensive retrofit solution sets to save energy and promote high IEQ in shopping centres, as well as the optimal environmental conditions for display and sale of merchandise. In a comparison with the pre-retrofit conditions, the project aimed to achieve a 75 % reduction of energy demand, power peak shaving, a 50 % increased share of energy used from Renewable Energy Sources (RES) compared to a base-case (renewables share so far), and an improved Indoor Environmental Quality (IEQ). The research was based on the demand for a comprehensive approach for the development of a retrofitting package for shopping centres, taking into account the specific needs of the building, such as indoor conditions, complex energy flows and the lack of standard energy intensity performance indicators (Bointner et al., 2014; Haase et al., 2015a; Haase et al., 2015b; Haase et al., 2015c).

Shopping centres are not interchangeable with other kinds of complex buildings, such as office blocks, hospitals or schools (ICSC, 2008; Stensson, 2014; Coleman, 2006). Their form, function, usage, and users give shopping centres a particular character with special implications for energy use (Coleman, 2006; Stensson, 2014; Woods et al., 2015; Woods et al., 2017). To support the understanding of what causes the main inefficiencies in energy usage and to enable the development of the best solution-sets, Bointner et al. (2014) developed a definition of shopping centres which describes shopping centres as "a formation of one or more retail buildings comprising units and 'communal' areas which are planned and managed as a single entity related in its location, size and type of shops to the trade area that it serves". The definition gives an indication of the main form and function of shopping centres. In addition, location, type of development, the size and GLA, the type of anchor stores and the trip purpose are all aspects that have been used to indicate the needs that a shopping centre serves within a social and physical context (Woods et al., 2015; Woods et al., 2017).

In the CommONEnergy project a number of solution-sets were developed starting from 11 real reference buildings located in different climatic, environmental, social and economic contexts, representative of the whole EU shopping centre building stock. Such solution-sets are tailored on architectural, constructive and technological features of this very special kind of building. Both energy load profiles and final uses are not comparable with other building categories, needing specific tools and dedicated approaches to achieve the best benefits/costs ratio. The analysis of 11 shopping centres in Europe (Fig. 1) reveals a lack of availability of indoor natural daylight, especially in shops and sales areas (Woods et al., 2015; Haase et al., 2015b).

Fig. 1 – The 11 different reference buildings

2. Objectives

The aim of this paper is to investigate the consequences on energy consumption and electricity use for lighting that novel retrofitting measures have, when applied to a Norwegian shopping centre.

3. Methodology

Together with detailed monitoring of energy use and indoor air quality, internal daylight and internal illuminance levels were measured in a shopping centre in Trondheim.

Scenarios were modelled to simulate the use patterns and control strategies of artificial lighting in the shopping centres considering occupancy hours and type of activity (illuminance levels), in order to cover different possible combinations used in the energy and daylight simulations.

The building was modelled in TRNSYS according to the plans and architectural drawings. A sketchup model (Fig.2) was developed and the functional units in the shopping mall were divided into common areas, shops, and others (Haase et al., 2015d). Existing conditions of the Norwegian shopping centre (pre-retrofitting) were modelled in TRNSYS based on the energy use measurements and energy and daylighting simulation were performed. Combinations of use pattern scenarios and facade variables were used for daylight and energy simulations in the retrofitted shopping centres to evaluate the influence on the electricity use of lighting and energy use of the combinations of the scenarios. Radiance was used for the lighting analysis (Ward, 1989).

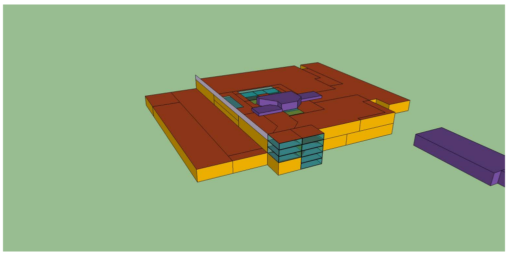

Fig. 2 – Sketchup model of the shopping centre from Haase et al. (2015d)

3.1 Energy Audit

The shopping centres that were analysed vary in size and energy use. Fig. 3 shows the share of gross leasable areas in the different reference buildings.

Fig. 3 shows that common areas cover 13 % of the gross leasable area (GLA) in all the shopping centres. Retrofitting measures will have an accordingly minor effect on the total energy use in shopping centres.

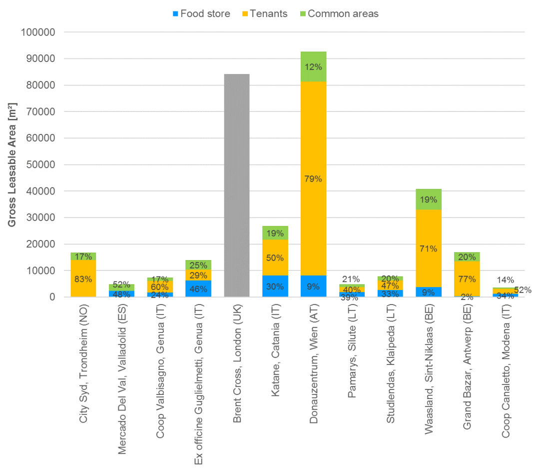

Fig. 3 – Gross leasable areas (GLA) of the different reference buildings

An identification and analysis of the current building energy behaviour was done in order to define the power peaks and the energetic balance in different time frames (from day to year). Technological active-installation check-ups were done in order to get a clear and detailed understanding of where and how the different facilities operate to match the building loads. An evaluation of the gathered data provided valuable input for the dynamic simulation platform, through a reverse engineering process, to compare generation and consumption profiles, highlighting overloads, overproductions, inefficiencies, lack of coordination, possible gaps and overlapping, necessities of shifting and storing among others, based and verified through the monitored data.

Fig. 4 shows that the simulated and measured electricity use in the Norwegian shopping centre match well.

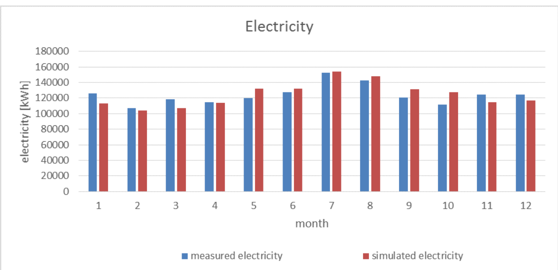

Fig. 4 – Validation of model with measured data

Finally, a definition of the energy retrofitting process – through the implementation in dynamic software of the novel developed and proposed concepts – was developed in order to verify the viability of the selected technologies and to assess foreseen results. The output of this analysis was used to define the baseline for the development of the control strategy for the improvement of existing technologies and the implementation of new ones.

3.2 Climatic Influence and Schedules

Sky conditions, especially the amount of sunny skies is different. Trondheim has few hours of clear blue sky. Opening hours are from 09:00 to 21:00, preparation hours are from 07:00 to 09:00 and night milieu hours are from 17:00 to 21:00 (see also Tab. 1 for further explanations of the lighting concept. Cases (3) and (4) introduce preparation periods.).

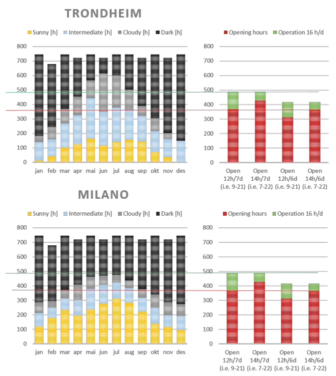

Fig. 5 – Sky conditions in Trondheim and opening hours of the shopping centre

Fig. 5 shows that almost during the whole year sunrise takes place before the opening hours. Bear in mind that even before sunrise and after sunset, it is not completely dark either. Preparation hours (restocking, cleaning, etc.) are often before sunrise/ after sunset. Cloudy and intermediate sky have brighter diffuse light levels than a blue sky.

3.3 LED Lighting

Description of the LED lighting strategy:

- Case (0)
- Case (1) New luminaires
- Case (2) constant light output (CLO)
- Case (3) zoning
- Case (4) night milieu with reduced intensity
- Case (5) light pipes

Each case is described in more detail in Tables 1 and 2. It can be seen that the resulting power per luminaire is reduced for Cases (1) to (5) compared to Case (0).

Table 1 – Lighting control strategy

Case	No. of luminaires	Control strategy	Power per luminaire [W]
(0)	43	constantly on during op. hours	70
(1)	57	constantly on during op. hours	37.72
(2)	57	constantly on during op. hours	33.86
(3)	57	+ PREP hours	27.02
(4)	57	+ PREP hours + day/night milieu	27.02
(5) Not daylit zone	31		32.26
(5) Daylit zone	26	+ light tubes	21.15

By installing three light tubes it was possible to reduce the lighting according to daylight illuminance. Table 2 shows the results of the nominal power for the demonstration shop area in the Trondheim shopping centre. Cases (1) to (3) reduce nominal power during opening hours. Cases (3) to (5) introduce additional preparation periods with reduced nominal power. Cases (4) and (5) introduce in addition a night milieu period with again reduced nominal power.

Table 2 – Lighting power installed in demonstration shop area

Case	Power per lum. (PREP) [W]	Nominal power during opening hours [kW]	during prep hours [kW]	during night milieu [kW]
(0)	-	3.39	-	-
(1)	-	2.15	-	-
(2)	-	1.93	-	-
(3)	18.95	1.54	1.08	-
(4)	18.95	1.54	1.08	1.08
(5) not daylit zone	22.58	1	0.7	0.7
(5) daylit zone	14.628	0.55	0.38	0.38

3.4 Light Tube Solutions

In one demonstration shop on the first floor of the shopping centre in Trondheim, a retrofitting to enhance daylight was conducted with three light tubes (see Fig. 6 for details).

The demonstration shop area was 100 m^2 (including 15 m^2 storage). Fig. 6 shows the plan and a section, Fig. 7 a photo. The diameter of each light tube is 1000 mm. Rooftop domes were placed on top of each light tube to provide air and water tightness.

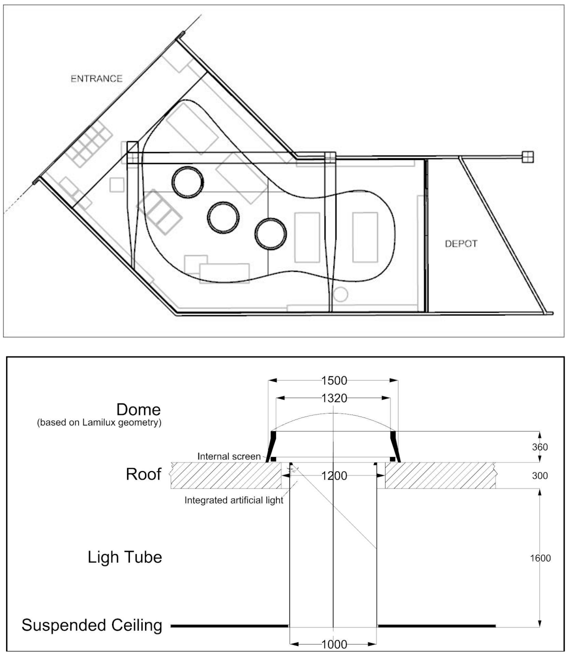

Fig. 6 – Plans of light tube solution in demonstration area

Fig. 7 – Photo of the light tube solution in demonstration area

4. Results

The implications of the installed power reductions of the cases (1) to (5) compared to case (0) are shown in Table 3. The mean specific power demand per area is reduced from 39.8 (case (0) to 16.5 W/m² (case (4)) and to 15.2 W/m² (case (5)) with luminous flux.
The implications of the different lighting retrofitting measures were then applied to the whole shopping centre. Two strategies were tested. First, the lighting retrofitting cases (1) to (5) were applied to the common areas (cma). Electricity savings were determined in primary energy (PE). Heating and cooling implications were determined. Secondly, the lighting retrofitting cases (1) to (5) were applied to the shop areas. Electricity savings were determined in primary energy (PE). Heating and cooling implications were determined.
The results from energy the simulations can be divided into electricity use, heating and cooling needs. Here, a focus was put on the lighting retrofitting measures, not on appliances nor on ventilation.

Table 3 – Results of the lighting strategy

Case	Specific yearly energy demand [kWh/m²a]	Mean specific power demand per area [W/m²]	Specific luminous flux per area [klm/m²]
(0)	178.2	39.8	2.06
(1)	113	25.3	1.69
(2)	102	22.8	1.69
(3)	77	17.2	1.28
(4)	74	16.5	1.23
(5)	68	15.2	1.23

4.1 Final Energy Use

Table 4 shows the heating and cooling implications. Cooling decreases from 20.1 kWh/(m² a)) (case (0) to 4 kWh/(m² a)) in cases (4) and (5). The need for heating increases from 49.5 kWh/(m² a)) (case (0)) to 70.4 kWh/(m² a) for case (4) and 84.3 kWh/(m² a) for case (5). Together with the electricity reduction from lighting the total also decreases from 206.8 kWh/(m² a)) (case (0)) to 124.4 kWh/(m² a) for case (4) and 119.5 kWh/(m² a) for case (5).
The changes are small when looking at the results for the common areas. Energy use for cooling decreases insignificantly from 20.1 kWh/(m² a) (case (0) to 19.4 kWh/(m² a) in case (4). Energy use for heating increases from 49.5 kWh/(m² a) (case (0) to 58.1 kWh/(m² a) in case (4).

Table 4 – Final energy use of lighting strategy in [kWh/(m² a)]

Case	area	Lighting	Heating	Cooling	Total
(0)	-	137.3	49.5	20.1	206.8
(1)	cma	121.6	57.2	19.5	198.3
	cma+shp	109.3	58.2	16.2	183.7
(2)	cma	120.9	57.5	19.5	197.9
	cma+shp	80.1	59.9	7.0	147.0
(3)	cma	120.1	57.8	19.4	197.3
	cma+shp	55	67.5	4.0	126.5
(4)	cma	119.4	58.1	19.4	196.9
	cma+shp	50	70.4	4.0	124.4
(5)	shops on first floor	31.2	84.3	4.0	119.5

4.2 Primary Energy Use

Fig. 8 shows the energy implications in Trondheim with cases (1) to (5) applied to different parts of the shopping centre.
Primary energy (PE) use for the whole shopping centre is 712 kWh_{PE}/(m² a). Primary energy (PE) use for case (0) for lighting is 343 kWh_{PE}/(m² a), for appliances 141 kWh_{PE}/(m² a), for ventilation 110 kWh_{PE}/(m² a), for heating 67.2 kWh_{PE}/(m² a), and for cooling 50 kWh_{PE}/(m² a).

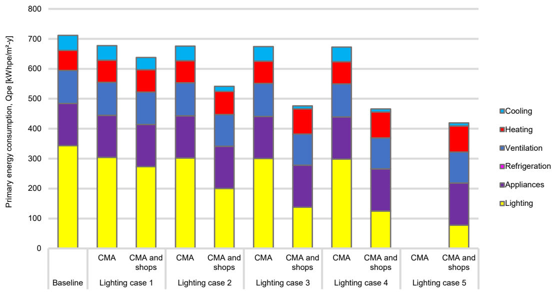

Fig. 8 – Primary energy use in Trondheim

Primary energy (PE) use for lighting can be reduced to 34 $kWh_{PE}/(m^2\ a)$ (4.8 % for case (1)) to 39 $kWh_{PE}/(m^2\ a)$ (5.5 % for case (4)) if applied to the common areas (cma). These are the typical areas, which are managed and maintained by the centre managers directly.

The application of lighting retrofitting cases (1) to (4) to all areas (cma and shops) results in PE savings of 74 $kWh_{PE}/(m^2\ a)$ (10.4 % for case (1)) to 246 $kWh_{PE}/(m^2\ a)$ (34.6 % for case (4)).

PE savings of 282 $kWh_{PE}/(m^2\ a)$ (39.6 % for case (5)) could be reached, if case (5) was applied to all suitable shops (all shops on the first floor).

5. Discussion

Existing conditions of the Norwegian shopping centres (pre-retrofitting) were modelled based on the energy use measurements and energy and daylighting simulations were performed. Combinations of use pattern scenarios and facade variables were used for the daylight and energy simulations in the retrofitted shopping centres to evaluate the influence on the electricity use of lighting and energy use of the combinations of the scenarios.

Together with the reduction of electricity employed for lighting, the total used for lighting, heating and cooling also decreases. However, the final energy use for heating increases.

PE savings of 35 % were possible with lighting retrofitting (case (4)) in common areas and shop areas. However, lighting retrofitting of shop areas is the responsibility of the shop owner/manager. It requires further engagement of these stakeholders to effectively implement lighting retrofitting solutions. These solutions save electricity (end energy use) but also influence heating and cooling end energy use.

The highest heating energy use is for case (5) (up to 84 $kWh/(m^2\ a)$). Even if the total energy use is minimized, an increase in heating demand requires additional investment in a heating system upgrade. In the next step, further measures should be applied to reduce energy use for heating to complement the lighting retrofitting strategy.

6. Conclusions

The work that formed the basis for this paper investigated the consequences on energy consumption and electricity use for lighting that novel retrofitting measures have when applied to a typical shopping centre. Lighting retrofitting results in a PE reduction of up to 40 %. The end energy use for lighting, heating and cooling also decreases. However, while end energy use for lighting and cooling decreases, the end energy use for heating increases.

There is a trade-off, which can be quantified in terms of reduction in electricity use and cooling demand as well as an increase in heating demand. As a consequence, existing window and roof structures needs to be further developed in order to give centre and shop managers a basis for decision making on refurbishment investments.

Shopping centre managers are usually responsible for providing heating (and often cooling, or at least cooling energy) to the shops. Lighting is usually in the responsibility of (each) shop owner/manager. The implications of lighting retrofitting on heating and cooling, aside from the end energy use savings, make the application complicated in shopping centres. The modelling and simulation of a shopping centre can help to understand the holistic consequences of single energy retrofitting measures. Aside from the straight forward end energy use savings (electricity), lighting retrofitting has implications for heating and cooling end energy use and primary energy savings. Shopping centre managers need to collaborate closely with shop owners/managers on energy retrofitting measures if the full potential is to be applied.

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Nomenclature

Symbols

cma	Common areas
shp	Shop areas
PE	Primary energy
PREP	Preparation period

References

Bointner, R., A. Toleikyte, R. Woods, B. Atanasiu, A. De Ferrari, C. Farinea, F. Noris. 2014. *Deliverable 2.1 report - Shopping malls features in EU-28 + Norway, EU FP7 project CommONEnergy – Reconceptualizing Shopping Malls*, access date: April 2015: http://www.commonenergyproject.eu/

Coleman, P. 2006. *Shopping environments: Evolution, planning and design.* Oxford, UK: Elsevier.

Haase, M., K.S. Skeie, R. Woods, S. Mellegård, R.D. Schlanbusch, S. Homolka, J. Gantner, S. Schneider, F. Lam-Nang. 2015a. *Deliverable 2.3 report - Typical functional patterns and socio-cultural context, EU FP7 project CommONEnergy – Reconceptualizing shopping malls*, access date: April 2015: http://www.commonenergyproject.eu/

Haase, M., R. Woods, S. Mellegård, K.S. Skeie, R. Lollini., F. Noris, J. Antolín. 2015b. *Deliverable 2.5 report - Main drivers for the deep retrofitting of shopping centres, EU FP7 project CommONEnergy – Reconceptualizing shopping malls*, access date: April 2015: http://www.commonenergyproject.eu/

Haase, M., R. Woods, K.S. Skeie. 2015c. "The key drivers for energy retrofitting of European shopping centres". *Energy Procedia* 78: 2298–2303. doi:10.1016/j.egypro.2015.11.368.

Haase, M., A. Belleri, C. Dipasquale, K.S. Skeie. 2015d. "Modelling of a complex building in Norway". In: *Proceedings of Building Simulation conference (BS2015)*. Hyderabad, India: IBPSA.

ICSC. 2008, *The Importance of Shopping Centres to the European Economy*. Access date Oct 2015: (http://sigs.icsc.org/srch/rsrch/wp/FINAL_Mar08_Complete%20WITH%20new%20cover%20and%20charts%20and%20tables.pdf)

Stensson, S. 2014. *Energy efficiency in shopping malls - some aspects based on a case study*. Göteborg, Sweden: Chalmers University of Technology.

TRNSYS, URL: http: // www. trnsys. com/.

Ward, G. 1989. "The RADIANCE lighting simulation and rendering system". In: *Proceedings of the 21st annual conference on computer graphics and interactive techniques*. New York, U.S.A: ACM.

Woods, R., S. Mellegård, R.D. Schlanbusch, M. Haase, K.S. Skeie, A. De Ferrari, M.V. Cambronero Vazquez, A. Ampenberger, R. Bointner. 2015. *Deliverable 2.2 report – Shopping mall inefficiencies, EU FP7 project CommONEnergy – Reconceptualizing shopping malls*, access date: April 2015: http://www.commonenergyproject.eu/

Woods, R., K.S. Skeie, M. Haase. 2017. "The influence of user behaviour on energy use in European shopping centres." *Sustainable Development* 25: 11–24. doi: 10.1002/sd.1638.