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LIGHTING POWERS IN SHOPS AND THEIR EFFECT ON THE ENERGY PERFORMANCE OF A SHOPPING MALL

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ABSTRACT

In this study, a multizone model of an existing shopping mall is developed in IDA Indoor Climate and Energy (IDA ICE). The model is validated using field measurements regarding use of energy for heating, sum of cooling and ventilation, operational electricity and tenant electricity. In addition, other input data used are energy use, operation hours, customer frequency, lighting, building envelope, HVAC system and control strategies. In this study, a parameter analysis regarding the building orientation, glazed façade area ratio and lighting is conducted. Results show that the shops' lighting powers dominate the cooling demand and imply that current internal loads decreases the sensitivity regarding energy demand of moderate changes in the glazed façades and building orientation.

INTRODUCTION

The prevalence of shopping malls is growing in Sweden, as in other parts of the world. Shopping malls represent technically complex buildings. They often have large internal heat loads due to extensive lighting and high population density. The use of glaze façades is also another common attribute. Lighting for exposure of goods is considered an important sales factor for the shops in the shopping mall. The *electricity use in shops* consists, almost exclusively, of lighting. Stensson, Axell et al. (2009) showed that 40-75 % of the total energy use in examined Swedish and Norwegian shopping malls was electricity use in shops. The contrasting interests of designing an aesthetically interesting design and maintaining a comfortable indoor climate, in some cases, tend to create buildings with a great cooling demand, despite the cold Scandinavian climate.

As the development of society moves towards a more sustainable and energy efficient path, the interest of looking at the potential of reducing the energy demand of shopping malls has grown.

The purpose of this paper is to evaluate the energy performance of an existing shopping mall. The aim is to identify the important aspects that are crucial for the energy demand of a shopping mall.

The method consists of simulations of an existing shopping mall, in the building simulation program IDA Indoor Climate & Energy (IDA ICE). First, a model of the reference building was developed to resemble the existing shopping mall with respect to indoor and outdoor temperatures, airflows, installed lighting, cooling and heating powers and total energy use. The model was preliminary validated using field measurements regarding use of energy for heating, sum of cooling and ventilation, operational electricity and tenant electricity. Regards were taken to local sky and climatic conditions, the climate file was produced from the software Meteonorm. Secondly, the developed model of the reference building was used for a parameter analysis. The parameters analysed in this paper are building orientation, glazed façade area ratio and lighting. See Table 1 for a summary of the simulations included in this paper.

Table 1
Overview of the simulations that have been conducted in this study.
(ref.=reference building)

PARAMETER ANALYSIS	
SIMULATED PARAMETERS	CHANGE IN SIMULATED PARAMETERS
Building orientation (Rotation angle rel. azimuth, º)	6 simulations: 0, 90, **130 (ref.) north-west**, 180, 270, 310 º. See also, Table 9.
Glazed facades (window façade area ratio, %)	5 simulations: 9, **17 (ref.)**, 25, 32, 46 %
Lighting (Installed lighting power, % of original model)	4 simulations: 50, 70, 90, **100 (ref.)** %

REFERENCE BUILDING

The reference building, a three-floor shopping mall situated near the West Coast of Sweden, opened in 2004. The two top floors contain shops with adjacent storerooms and a bottom floor, beneath ground level, consisting of a car park, offices and staff rooms. The fan room and cooling machines are also in the basement. Dry coolers, Air Handling

Units (AHUs) and heat exchangers for free-cooling are situated on the roof. The main entrance faces north-west andconsists of a large glazed façade, see Figure 1. This glazed façade's area ratio to the total wall area of the entire shopping mall is 17 %. The mean yearly lighting power is predicted to be 37.5 W/m^2. The prediction, which is based on energy use data and operation hours, is explained further in the section about the simulation model.

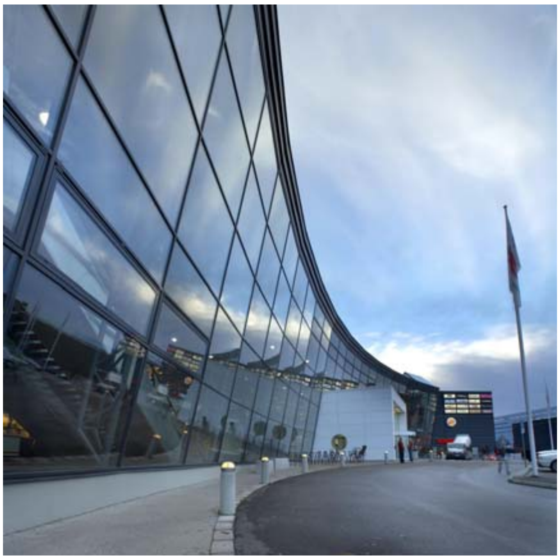

Figure 1 Photo of the reference building's glazed façade.

The reference building's installations

Electricity is the primary source of energy for both heating and cooling. Figure 2 shows the shopping mall's energy use distribution in percentage.

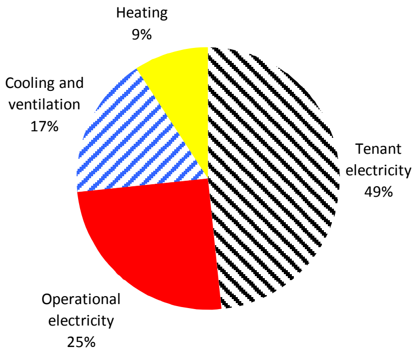

Figure 2 Distribution of electricity use by percentage in the reference building divided between: electricity use in shops, electricity for building operation, space cooling and ventilation, and space heating.

Space heating in the reference building

When the building has a heating demand, the heat is generated by two electric boilers and distributed to the indivudual shops via the heating coils in the AHUs. Radiators (both water and direct power) heat spaces such as corridors, stairwells and staff rooms. The inside part of the entrance is equipped with heating coils in the floor. The outside part of the entrance is equipped with electric ground heaters to keep away snow and ice. Front entrances and rear loading gates to the shops are also equipped with air curtains.

Space cooling in the reference building

Space cooling is produced locally by two chillers and distributed via brine circuits to the cooling coils in the AHUs and to the shops' passive chilled beams. Whenever possible, free-cooling is used, meaning that outdoor air is used for cooling of the brine. This decreases the operation time for the compressors.

Ventilation in the reference building

The ventilation system is a constant air volume system. It is divided in six zones, each supplied by its own AHU. Heat is recovered through a rotating, non-hygroscopic and axial driven, heat exchanger with a temperature efficiency of 74 % (manufacturing data). The supply air temperature is controlled depending on the outdoor temperature. The air is conditioned by the cooling and heating coils in the AHUs and supplied to the shops via ducting. The exhaust air is taken from the general spaces in floor 3 and from the shop storerooms in floor 2 and then returned to the AHUs. The fans are frequency controlled to maintain constant static pressure. To complement the AHUs, there are mechanically and manually controlled windows placed in the glazed façade entrance.

Other installations in the reference building

Other important equipment from an energy perspective, and hence included in the energy balance are two elevators, four escalators and two walkways.

SIMULATION MODEL

The simulation software used is IDA ICE 3.0 and 4.0 Beta. IDA ICE is a program for energy and indoor climate simulation of whole buildings. The program has been validated, for example, in the project IEA Task 22 (Building Energy Analysis Tools) and BESTEST (Poirazes, H 2008). In Figure 3, a 3-D view generated from IDA 4.0 Beta is shown.

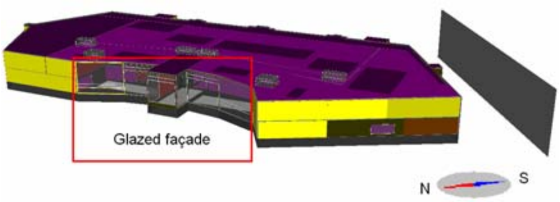

Figure 3 View of the simulation model from the northwest, with adjacent shading building to the right.

Multiple zones

The simulation model consists of 26 zones in total, of which 14 are shop zones. Figure 4 shows the zone division for floor 2 of the model.

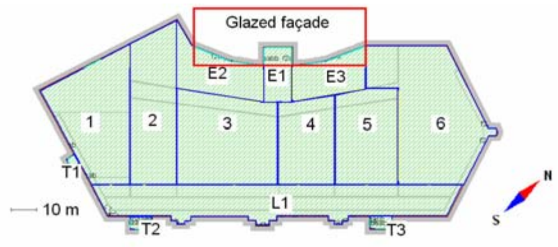

Figure 4 Zone division for floor 2; 1-6 Shop zones, E 1-E 3 Entrance zones, L 1 Storeroom zones, T 1-T 3 Stairwell zone.

When too simplistic zone divisions with too large zones are used, the energy demand for the building tends to decrease. During simulations in other studies of offices; an open office design (one large zone) gave 57 % lower energy demand compared to the same area divided in several small zones (Poirazis 2008).

The reference building is equipped with water and electric radiators in corridors and staff spaces, which are also included in the simulation model. To obtain accurate transmission losses, an extra zone adjacent to the exterior wall was added. Other zones that have been added to achieve better simulation results of the heating demand are; the stairwells and a zone in the basement.

The reference building has a parking space in the basement that consists of an unheated space with open exits. To account for this, a separate simulation was conducted and the resulting air temperature was added to the main model by a data file directly connected to the slab of floor 2. The reason for this was to decrease simulation time. Figure 5 shows how the temperature in the garage varies over the year compared to outdoor temperatures. The fluctuations of temperatures is in phase with the outdoor temperatures, however the amplitude is somewhat decreased.

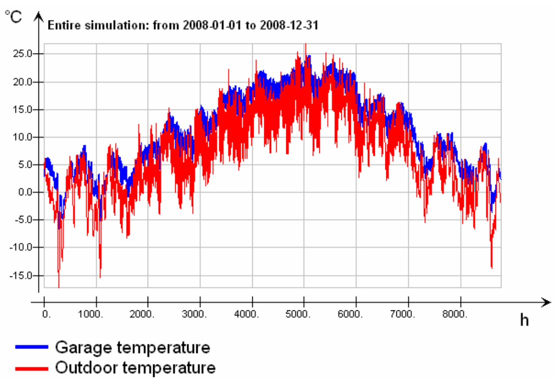

Figure 5 Air temperatures in the parking space in comparison with the outdoor temperatures.

Geographical location

The shopping mall's geographical location is in the city of Trollhättan. See Table 2. A climate data file for the location was created in the program Meteonorm.

Table 2
Building orientation.

GEOGRAPHIC COORDINATES		
Longitude	E 12,31°	18' 32,05"
Latitude	N 58,31°	18' 47,10"

Daylight

Daylight is provided to the building mainly through the glazed façade. Further, daylight enters the building through the skylights. To simulate the skylight's affect on the building's energy balance there is a special calculation macro in IDA ICE. The skylight is regarded as a temperate surface from the zone's perspective. The surface is calculated based on a weighted value of the temperatures of the glaze and of the other surrounding surfaces. The downdraughts from these windows are not modelled in detail.

Operation hours

The operation hours that were used in the simulations are shown in Table 3.

Table 3
The shopping mall's operation hours.

EQUIPMENT	SCHEDULE	OPERATING HOURS PER YEAR
Shop lighting	Monday - Friday. (9.15-19.15), Saturday. (9.15-17.15) Sunday. (10.15-17.15)	3380
Lighting common spaces	Monday – Sunday. (6-21)	4380
Fans	Monday - Sunday. (7.50-19.30). Also, controlled cooling through night ventilation.	4258 + Operation time night ventilation
Chillers	Monday - Friday. (7-21) Saturday. (7-21) Sunday. (7-21)	4015

Internal heat loads from people

Customers influence the internal heat loads since they emitted both sensible and latent heat. When simulating the building's energy balance, it is necessary to know the heat emitted from people in the building. During simulations of the thermal environment, ISO 7730 is used to specify the people load in IDA ICE. Table 4 shows the assumed activity for customers and staff.

Table 4
Input data according to Fanger's comfort index.

TYPE	ZONE	METABOLISM (MET)	POWER (W)	CORRESPONDING ACTIVITY
Customer	Shops	1.7	180	Office work walking
Customer	Entrance/ corridors	2.0	207	Walking 3.2 km/h
Staff	Shops	2.1	216	Office work lift/packing

Figure 6 shows the people load intensity during a Wednesday, Saturday and Sunday. There is a large deviation in the internal heat loads, due to people, between open and closed hours. There is also a large difference between the number of people visiting the shopping mall during Saturdays as compared to Wednesdays and Sundays.

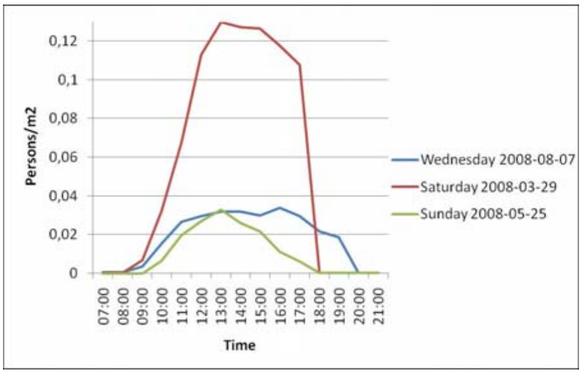

Figure 6 People density variations over a Wednesday, Saturday and Sunday.

Lighting

During simulations of the reference building, data of actual energy usages have been used along with the operation hours to calculate approximate mean yearly power per square metre, W/m^2. It is assumed that the electricity used in the shops mainly goes to lighting. To meet the shops requirement for hot water each shop is equipped with an electric hot water heater. Since input data regarding power, heat rejection and operation hours for these hot water heaters is missing, these have been excluded from the simulations and been assumed to constitute 2 % of the tenants' electricity use. Used lighting power and total electricity used by the tenants are found in Table 5.

The simulation program is limited to one model for the lighting for each zone. Further, there are limited possibilities to define the area of the light fixture.

Table 5
Lighting power and total energy demand.

SIMULATION	REFERENCE BUILDING
Lighting power W/m^2	37.5
Total electricity used by the tenants MWh/year	2068

Building envelope

The U-values for the building envelop is presented in Table 6.

Table 6
U-values used for the model's construction part.

CONSTRUCTION PART	U-VALUES W x m^{-2} x K^{-1}
Walls	0.23
Glazed façade	1.9
Roof	0.25
Floor	2.38

Ventilation

Figure 7 shows a principle sketch of the AHU. The system is controlled towards three different operation modes;

- Winter: when the outdoor air temperature is below 5 ˚C
- Spring/autumn: when the outdoor air temperature is between 5 ˚C and 12 ˚C
- Summer/night: cooling when the outdoor air temperature is above 12 ˚C

For winter operation, 50 % re-circulation is used. When the outdoor air temperature is above 5 ˚C no air is re-circulated. The supply air temperature is always kept constant at 17 ˚C; the air heaters heat the supply air to 16 ˚C and the remaining 1 ˚C is obtained from the temperature rise over the fan.

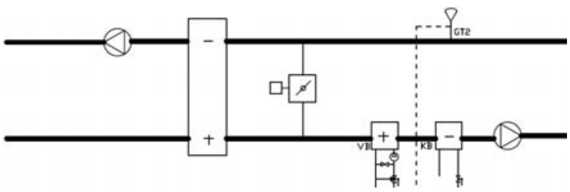

Figure 7 Principle scheme of the ventilation system in the model.

The airflow rates for the ventilation have been stated according to the mandatory ventilation inspection (in Swedish OVK-protokoll). The main airflows for the supply and exhaust air are given in Table 7. The airflow rates have a large impact on the calculated results with respect to the energy demand. A prerequisite to increase the validity of the model is to complement the OVK with field measurements.

Table 7
Approximated airflows through the central air unit.

FLOW DIRECTION	FLOW LITRE/SECOND
Supply air	34650
Exhaust air	27000

Cooling plant

The simulations are performed using the built in ideal chiller of the IDA ICE plant model. A principle sketch of the cooling plant is shown in Figure 8.

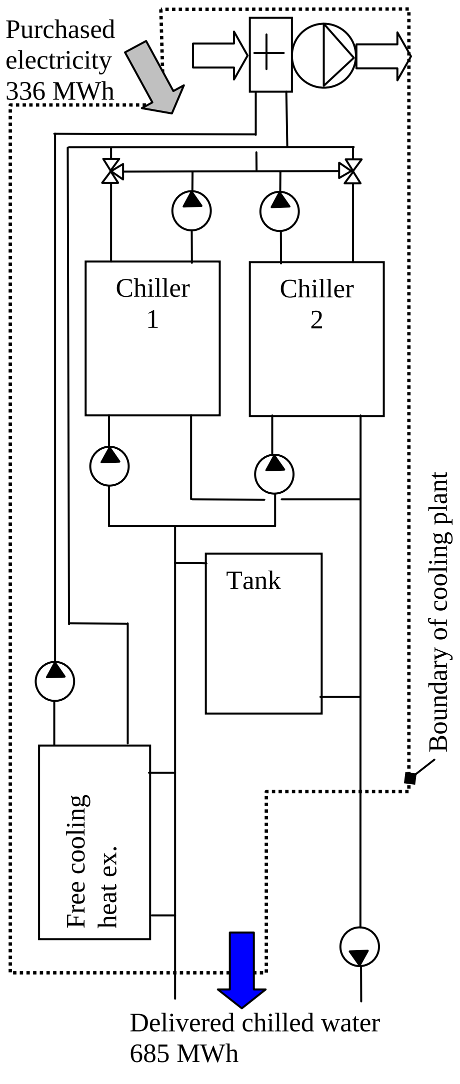

Figure 8 Principle scheme of the cooling plant in the model. The definition of COP_{system} in this paper is defined as delivered chilled water divided by purchased electricity to the cooling plant.

The cooling system was modelled separately using the results from the building simulations as input data to estimate the annual performance of the cooling system. In this stage of the project, the model is not yet calibrated, hence the output is preliminary. The actual total use of electricity for ventilation and cooling is approximately 36 kWh/m^2. Of this approximately 20 kWh/m^2 is needed for ventilation. Therefore, the use of 16.1 kWh/m^2 for cooling looks reasonable, see Table 8. Simulations indicate an annual COP_{system} (Coefficient Of Performance) for the cooling system of 2.0. The COP_{system}, in this paper, is defined as delivered chilled water divided by purchased electricity to the cooling plant. The cooling system delivers about 685 MWh from which 150 MWh is 'free-cooling'. Free-cooling, as it is used here, refers to the possibility of using outdoor air for cooling the brine, decreasing the operating time for the compressors. The yearly energy use of electricity is 175 MWh for fans and pumps and 161 MWh for chillers. For specific energy usages, see Table 8. The pumps for distribution of the brine to the AHUs and chilled beams use about 5 MWh/year which is not included in the calculation of the annual COP_{system}. The COP_{system} for the free-cooling during the winter is estimated to be about 6.6 using values for January. If the free-cooling is removed, the COP_{system} will decrease to about 1.8.

Table 8
The yearly energy used in the cooling plant. The total need for cooling is 685 MWh/year.

ENERGY USER	MWh/YEAR	kWh/m^2
Compressors	161	7.7
Pumps	71	3.4
Condenser fans	104	5
TOTAL	336	16.1

RESULTS

Building orientation

A common location for shopping malls is in the outskirts of cities. Depending on the shopping mall's surroundings, different requirements for the building orientation are needed. To illustrate the influence on the energy performance due to building orientation, the model has been rotated. The orientation is defined as the entrance façade's counter clockwise rotation in degrees (º), where 0º is when the entrance is facing south, see Table 9.

Table 9
Building orientation for the different simulations.

ROTATION, αº	ORIENTATION
0	South facing
90	West facing
130	Original orientation
180	North facing
270	East facing
310	Southeast facing

Figure 9 shows the building's total energy demand for various building orientations. Note that the scale on the y-axis is truncated. The differences in total energy demand are rather small, with a variation below 0.6 %, shown in Figure 10. Further, there are no significant differences in cooling or heating demand either, which is shown in Figure 11. As expected, the cooling demand is lowest for the two cases where the glazed façade is oriented in a northerly and a northeasterly direction. Because of the building's northern direction, these two cases have the least amount of heat supplied through daylight.

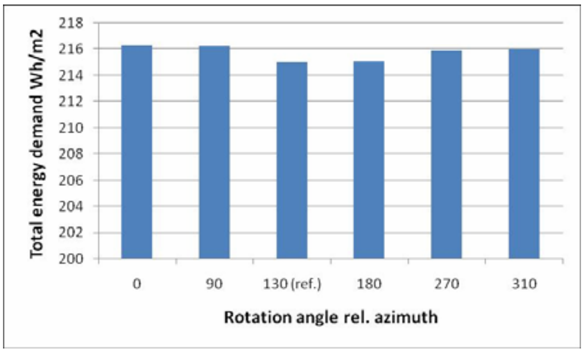

Figure 9 The building's total energy demand (kWh/m^2) with respect to building orientation.

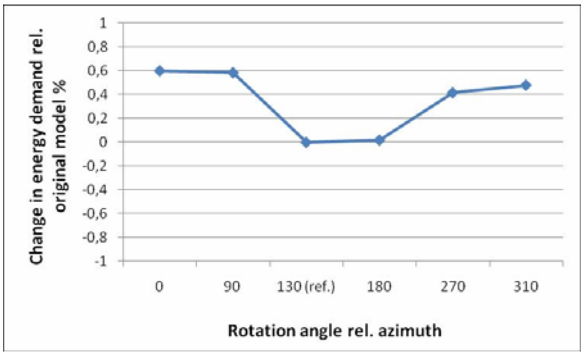

Figure 10 Percentage of change in energy demand dependent on the building's orientation.

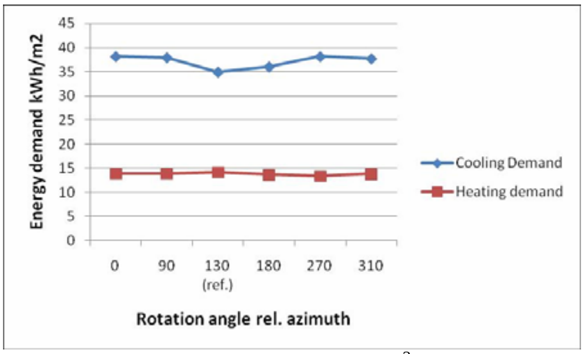

Figure 11 Energy demands (kWh/m^2) for cooling and heating for different building orientations.

These results apply for the building as a whole. However, further simulations of separate building zones showed that the building orientation affects the interplay between daylight dependent loads, such as the heat supply from daylight, supplied/emitted heat in construction parts and supplied/removed heat through ventilation. As an example, when the entrance zones faced west and east it caused larger ventilation loads than for other orientations. Although the building orientation has an impact on different zones, the total energy demand for the building as a whole remains stable. These results might change however when other heat loads, i.e. lighting, are changed. Further investigations concerning this issue will be conducted.

Glazed façades

Glazed façades are becoming a common feature when architects strive to design aesthetical shopping malls attractive to customers. These façades require greater consideration from designers when it comes to calculating both the heating and cooling loads.

Figure 12 shows how the energy demand varies depending on the ratio between window and wall area. The energy demand decreases for a smaller increase in glazing as compared to the reference building. It could be expected that the energy use either increase or decrease linearly when the window size increases. However, in this case, the location of the window is important because the building is actually shading itself. This might explain that the results are not linear. An optimum percentage of glazing is suggested at approximately 32 %, but this could most likely fall within the model's margin of error. As can be seen in Figure 13, there is no significant difference in energy demand when the 'window façade area ratio' is varied from 9 % to 46 %. As for the study of the building orientation, this indicates that the building's energy demand is less dependent on parameters outside the building. However, with larger glazed façades more heat is added through daylight affecting the cooling and heating demands, as can be seen in Figure 14.

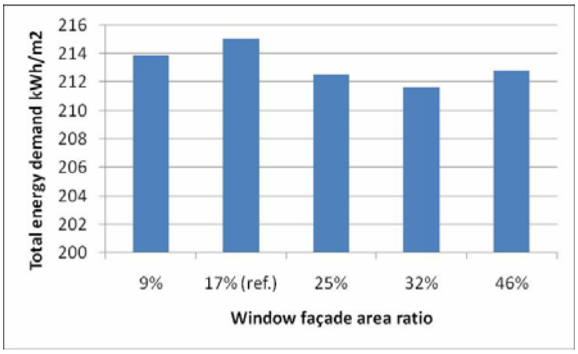

Figure 12 The building's total energy demand (kWh/m^2) with respect to the 'window façade area ratio'.

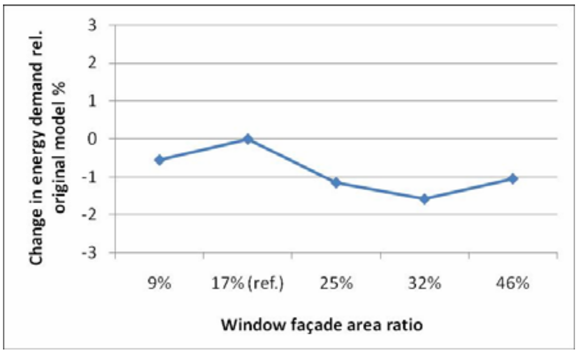

Figure 13 Percentage of change in energy demand dependent on the 'window façade area ratio'.

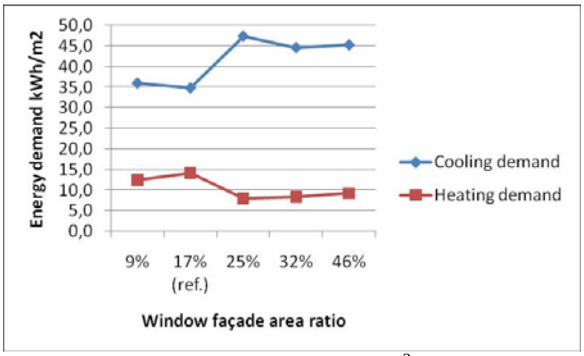

Figure 14 Energy demands (kWh/m²) for cooling and heating for different window façade area ratios.

Lighting

During the past few years, there has been a trend towards shops installing more lighting, for the purpose of greater exposure of commodities. This is believed to increase sales. Simulated energy demand for different lighting powers in the shops is shown in Figure 15. A significant difference in the building's total energy demand is obtained already at a 30 % decrease in lighting power, which could be a reasonable level within a near future. The Eco-design Directive of energy using products (EuP) adapted by the European Union (2005) sets the minimum requirements for energy efficiency and functionality for lighting. This directive along with emerging technologies for energy efficient lighting systems will most likely change the characteristics of the heating loads originating from lighting in shopping malls.

Lighting, in contrast to building orientation and ratio of glazed façade, has a significant impact on the total energy use of the shopping mall. The percentage of change in energy demand is shown in Figure 16. A decrease of the installed lighting power by 10 % in the shop zones results in a decrease of the whole building's total energy demand with more than 5 %.

A comparison between supply and removal of thermal energy is shown in Figure 17. Further, Figure 18 shows the demand for bought energy, under the assumption that $COP_{system} = 2$.

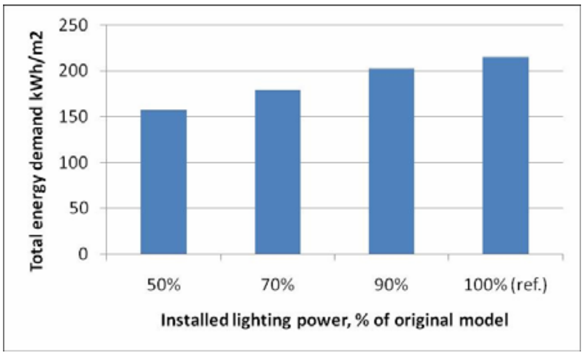

Figure 15 The building's total energy demand (kWh/m²) with respect to installed lighting power.

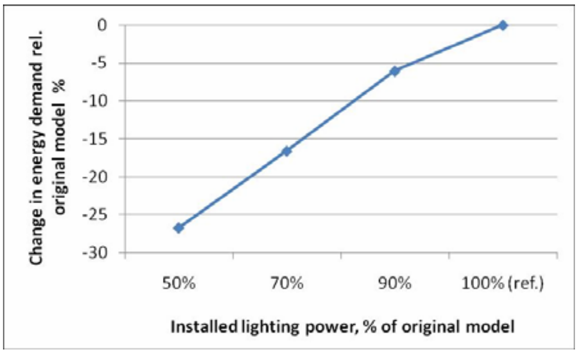

Figure 16 Percentage of change in energy demand dependent on the installed lighting power.

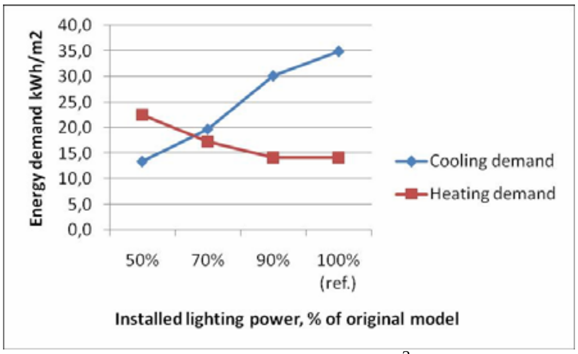

Figure 17 Energy demands (kWh/m²) for cooling and heating for different installed lighting powers.

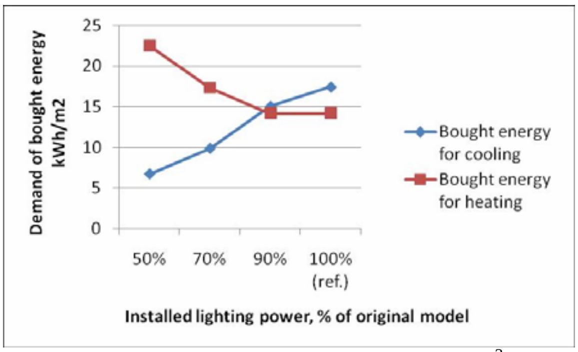

Figure 18 Demand of bought energy (kWh/m²) for heating and cooling depending on installed lighting power in the model's shop zones.

DISCUSSION

The prevalence of shopping malls is growing worldwide and with development of society towards a more sustainable environment, architects and designers are facing the challenge of improving the energy performance of shopping malls. Not only will regulations, like EuP, require a more energy efficient future, but cost reduction and marketing of environmental awareness might be an even stonger incentive. However, research on energy performance of shopping malls is still limited. Also, practitioners too often lack knowledge on how the energy is distributed between functions in these buildings. Ways to deal with these problems are through field measurements and simulations.

In this paper, a model of an existing shopping mall has been developed and simulated in the software program IDA ICE. The aim is to identify important aspects that are crucial for the energy demand. The parameters of main interest were; use of artificial light, glazed façades (window façade area ratio) and building orientation.

Results show that shops' lighting power dominate the cooling demand and implies that the size of the current internal loads make the energy demand less sensitive to changes in the façades and the orientation of the building. For lighting, there is an obvious difference in the building's total energy demand obtained already when the lighting power is decreased by 30 %. One of the simulations investigated a 50 % reduction of the current lighting power. The results show that there is a large potential to lower the building's total energy demand without drastically increasing the heating demand.

Of the three parameters; building orientation, window façade area ratio and lighting power, it is actually fortunate that the lighting power has the largest impact on the energy demand and is the only parameter that can be influenced for existing buildings. Lessons learned from studying the other two parameters can of course be implemented when designing new buildings. It is recommended to account for lower lighting power when designing new buildings and planning energy measures in existing buildings, since regulations such as EuP is expected to decrease installed lighting powers.

The results presented in this paper are interesting to keep in mind while considering that new lighting technology is advancing. Once the heat load from lighting is decreased, other aspects will become more important. For accurate prediction of a future situation, further studies will be conducted. This paper is part of a research project that will continue to refine, validate and use the simulation model described.

CONCLUSION

Building simulations of an existing shopping mall in Sweden shows that, for this geographical location, neither the orientation of the building nor the percentage of glass in the façade have any impact on the total use of energy. However the proportion between the different users will most likely change in the future, i.e. lighting will most likely decrease because of EuP. Decreasing the use of lighting shows a great potential for savings, because the total use of energy decreases by approximately 5 % for each 10 % decrease of the lighting power.

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