




## Article

# Effects on Energy Demand in an Office Building Considering Location, Orientation, Façade Design and Internal Heat Gains—A Parametric Study

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**Abstract:** 12.9% of the energy use in the EU originates from the commercial and public sector. It has therefore become a priority to optimize energy efficiency in these buildings. The purpose of this study has been to explore how energy demand in a new office building is affected by different internal heat gains, location, orientation, and façade design, and also to see how different indicators can change perspective on energy efficiency. The study was performed with simulations in IDA-ICE with different façade design and changes in internal heat gains (IHG), orientation, and location. Energy demand was then compared to two different indicators. Using a façade designed to lower solar heat gains had little effect on energy demand in the north of Sweden, but slightly more effect further south. The amount of internal heat gains had significant effect on energy demand. Making deeper studies on design and internal heat gains should therefore be prioritized in the beginning of new building projects so the most energy-efficient design can be chosen. When the indicator kWh/m<sup>2</sup> was used, the cases with low internal heat gains were perceived as the most energy efficient, while when kWh/(m<sup>2</sup> × hpers) (hpers = hours of use) was used, the cases with high occupancy and low electricity use were considered to be the most energy efficient. Therefore, revising the standardized indicator is of great importance.

**Keywords:** building energy simulation; energy efficiency indicators; internal heat gains; occupant behavior; parametric study

## 1. Introduction

The share of energy use from the commercial and public sector was 8.1% globally, and 12.9% in the EU. The sector accounted for 2.1% of the global CO<sub>2</sub>-eq emissions and 5% of the emissions from the EU in 2017, according to IEA [1]. Given the high levels of energy use and CO<sub>2</sub>-eq emissions from large non-domestic buildings, it has become a priority to optimize their energy efficiency [2]. There is also a high potential for reducing energy use in buildings, and the design phase is very important for this purpose [3]. It can however be difficult to predict occupancy behavior, which has a vital impact on the energy performance gap between predicted energy use and the actual energy use of an existing building [4], and a major concern for facility managers is how to evaluate and forecast the energy demand of a building [5]. Moreover, as building characteristics technically improve to reduce energy use, the behavior of occupants has a relatively increasing impact on which type of energy is used. Unfortunately, there is rarely enough time to do in-depth studies on different designs in the design phase.

Today, in Sweden, most building projects start with the customers setting out specific demands for the building, then the consultants and building contractor get involved, and finally the supplier will be engaged and the project starts. One of the first things that happens in a regular project is that an architect generates some ideas on the building esthetics and from those ideas it is up to the engineers to try to fit all components and functions within the building envelope. A big difference between architects in Sweden and other countries is that architects in Sweden are focused mainly on esthetics and seldom on the technical aspects of building construction.

Deciding which indicator to use when assessing energy efficiency in a building is also vital so that the right energy efficiency measures are encouraged [3], which for instance could be using windows with lower  $U$ -values or increasing insulation if an indicator that takes more technical aspects into consideration is used. If, for example, an indicator mapping the occupancy hour is used, a measure could instead be to try and increase the occupancy time in a building. A building with high occupancy and good space efficiency can in fact appear to be less energy efficient than a similar building with lower occupancy if energy efficiency is measured in  $\text{kWh}/(\text{m}^2 \times \text{year})$  [2,6]. This happens because the energy use that is dependent on number of users is high, thus affecting the heat balance of the building, such that energy for heating and cooling to the building is decreased or increased, respectively, while the floor area remains the same [2,6]. It is therefore important to understand how building occupancy, space efficiency, and energy use are related [3]. Occupancy not only affects the internal heat gains in a building by sheer heat emanating from the occupants themselves but also, and mostly, from the electrical equipment they use, at least in an office building. The more people that work in an office building, usually the more computers and other office equipment are needed and used. It is important to keep in mind that, in the future, office staff might be working in a different way. There are studies showing that employees will probably work more from home in the future [6–9], which might lead to lower internal heat gains. This has become a reality much faster than anticipated now in 2020 due to the global pandemic of COVID-19, which has forced people to work from home as they have not been allowed to go to their offices or been told to avoid going there if possible [10]. There is also a large probability that office equipment such as computers and computer screens will continue to become more energy efficient, also leading to lower internal heat gains as long as the trend to get more electrical equipment per capita does not increase.

Another interesting aspect to explore is the possibility of using an office building for longer periods of the day, and/or to use it for other activities during evenings, weekends, and holidays. This could increase the number of hours that the building is used during its lifetime in order to use the resources more efficiently. In Reference [3], the authors used six different indicators for measuring energy efficiency in five different case studies. They conclude that, while  $\text{kWh}/\text{m}^2$  is very useful in the design phase when comparing technical solutions and easy to calculate, it does not take space efficiency into account. According to Reference [3],  $\text{kWh}/(\text{m}^2 \times \text{hpers})$  ( $\text{hpers}$  = sum of the number of hours that each building occupant spends in the building during the year in question) has the advantage that it takes both occupancy hours and space into account, but it overestimates the effect of space and person hour efficiency in an exponential way. They conclude that  $\text{kWh}/(\text{m}^2 \times u)$  is the best indicator, but it is very hard to calculate and is only applicable in buildings that are already in use ( $u = (nt_{\text{avg}})/(A/a_{\text{ref}} \times t_{\text{ref}})$ ), where  $n$  is the actual number of people using the space,  $t_{\text{avg}}$  is the average number of daily hours present per person,  $A$  is the total studied area,  $a_{\text{ref}}$  and  $t_{\text{ref}}$  are normalizing factors,  $a_{\text{ref}}$  is the amount of space per person available in a typical office setting and  $t_{\text{ref}}$  represents normal working hours.  $\text{kWh}/\text{m}^2$  is still the most commonly used engineering indicator for building energy efficiency, and most studies on office buildings in recent literature focus on the technical characteristics or technical systems of the buildings [3]. If  $\text{kWh}/\text{m}^2$  is used when assessing energy efficiency in a new office building, one will probably end up with a building that stands empty most hours of the day, and it will probably not be very space efficient. This could be called a waste of space and energy, and instead of having office buildings mostly standing empty after quitting hours, many real-estate companies and their tenants are trying to find ways to prolong the hours of use in their buildings [11]. How this could affect

heating and cooling demand of an office building is the aim of the present investigation, along with a different amount of internal heat gains, façade designs, orientation, and location.

Location is interesting since in Sweden there is quite a difference in the outdoor climate as the country stretches over a long latitude span and building energy demand is highly correlated to outdoor temperature. In Reference [12], the authors conducted a parametric study of a cellular office room using the simulation tool EnergyPlus. They used two different occupancy scenarios, each compared with three different architectural design variations and had the office room located in three different locations: Athens, Alice Springs, and Hamburg. They conclude that occupants are the predominant influence on office final energy consumption in all investigated climates and that warmer climates seem to have larger optimization potential for comfort and energy performance in offices compared to colder climates. The authors of Reference [13] conducted a parametric study, using the energy and indoor climate simulation software WUFI®Plus v3.1.0.3, to investigate the potential and limitations of a passive building design in Malta with a focus on thermal comfort. The passive building was an office and the parameters investigated was orientation, window-to-wall ratio, glazing, shading device, thermal insulation, nighttime ventilation, and thermal mass. They concluded that a high level of thermal comfort is achievable by using very minor amounts of energy for heating and cooling in a Mediterranean climate by means of decent insulation, double glazed windows, variable shading devices and passive cooling by nighttime ventilation. A sensitivity analysis was conducted in Reference [14] to analyze the influence of solar transmittance of windows, indoor operative temperature set-points, model of mass distribution in building components and occupancy density of the heating and cooling demands and loads of a building. The authors conclude that operative temperature set-point is the main influencing parameter, and that occupancy density also has a large influence, especially during the cooling period. A parametric study of the effect on cooling and heating demand of an office due to different solar shading strategies and window types in a cold climate was performed in Reference [15]. The authors simulated office cubicles with Norwegian passive house standard using EnergyPlus, assessing the energy demand for heating, cooling, lighting and ventilation. They concluded that energy demand can be affected by the choice of solar shading strategy and can either increase or decrease compared to a non-shaded office. Solar shading in north-facing offices has an insignificant effect on energy savings, and is more likely to increase the energy demand while having a four-paned window is always better than having a two or three-paned window. In south-facing offices however, the right strategy for solar shading can lower the energy demand by up to 9%. In Reference [16], the authors performed a parametric study of an office building using the building energy simulation software IDA-ICE. They compared two different models of an office building, the difference being that one was constructed according to Swedish building standards and the other was constructed as a low-energy building. The model was simulated with low internal heat gains and is located in Stockholm. In the parametric study, they investigated design features impacting energy use in order to suggest the optimal low-energy design from a Swedish perspective. Their conclusions were that, in order to achieve a low-energy office building in Stockholm, a reasonable window to wall ratio is necessary, demand controlled ventilation should be used, demand can be controlled and low energy lighting and equipment should also be used. Further, a wider range for temperature set-points is of importance as well as having a well-insulated and air-tight building envelope. They also state that, for low-energy offices, it is crucial to decrease user related electricity and internal heat gains. The above mentioned References [12–16] confirm that building energy simulation is an appropriate tool to analyze the thermal performance of buildings. In this paper, a parametric study was used to investigate the effects of the above-mentioned parameters: location, orientation, amount of internal heat gains, solar shading and façade design of an office buildings heating and cooling demand. The investigation was conducted using building energy simulation in the software IDA-ICE v4.8. The present study will show that all these parameters are important to take into consideration when designing office buildings. Energy use in the studied office building will also be compared to two different indicators, kWh/m<sup>2</sup> and kWh/(m<sup>2</sup> × hpers), to show how this can affect how energy efficiency is perceived. The novelty, to the best of the

authors' knowledge, is that the studied specific type of façade, so called saw-toothed/angled façade, has not been investigated previously and is not common in the setting of a Nordic climate. Several parameters affecting the energy demand representing a broad range of conditions in cold climate are used in the parametric study. The study is of importance since user behavior has a significant impact on energy demand, both in commercial and residential buildings and studies of the impact of behavior on energy demand in commercial and public buildings are scarce according to Reference [17]. The objective of the present study is to explore the following research questions:

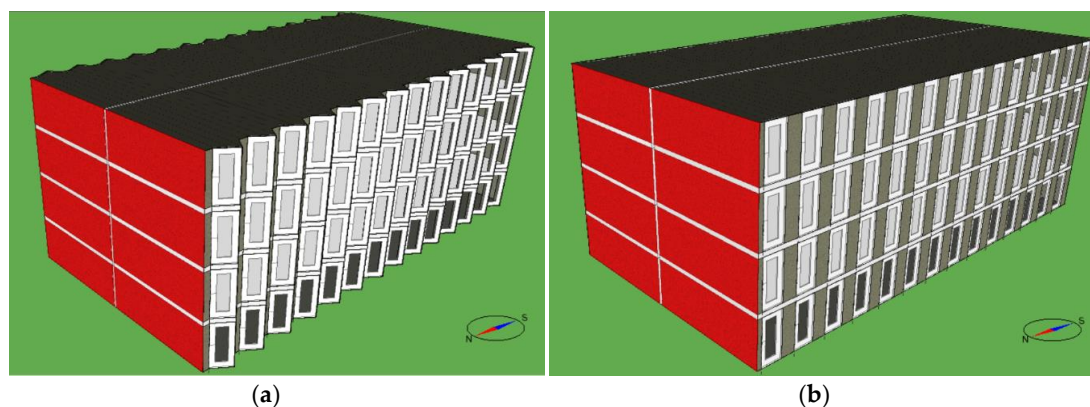
How will heating and cooling demand in a new office building, located at different latitudes in Sweden, be affected by increased or decreased internal heat gains?

How does a façade designed to lower solar heat gains affect heating and cooling demand in a new office building at different latitudes in Sweden?

How does the choice of indicator for assessing energy efficiency affect which level of internal heat gains can be considered best from an energy efficiency point of view?

## 2. Case Study

The object used as inspiration in this study is a new office building that is planned in the city of Linköping, Sweden. It is designed to use less cooling by having an angled façade so that the windows are directed more to the northeast and northwest instead of directly to the east and west (on the eastern and western façades), see Figure 1. The building was ordered by the municipally owned real estate company Sankt Kors (Linköping, Sweden), which mainly manages office buildings. In a pre-study performed by Sankt Kors at the beginning of the project, they tried to determine the degree of angle that the windows should have to get the lowest possible cooling demand. The degree of angle was decided to be between  $10^\circ$  and  $35^\circ$  by the architect, and it turned out that the larger the angle, the less cooling is needed, therefore the angle of the windows was set to  $35^\circ$  in the project and also in this study.



**Figure 1.** (a) The studied model with an angled façade and (b) the studied model with a straight façade. For both models, the reference surface is the short side without windows, directed to the north (in the standard case) and marked with red in the figure.

Sankt Kors is currently interested, as are many other real estate companies [11], in finding ways to extend the occupants' visiting hours in their facilities. One way could be to let out the offices to, for example, gaming communities or other associations during the evening and weekends or have areas for leisure activities in the offices that can be used by those who work in the building. One company, for instance, is using their offices to house laid-back performances from upcoming artists after-hours, which is both good for the artist and also gives exposure to the company [11]. Another company hosts happy hours and/or lets their tenants host happy hours. Investing in a projector and hosting movie nights for the tenants is yet another idea [11]. Some more uses of after-hours office space include networking, meet-ups, co-working, exercise/fitness, international offices, and even band practice [11].

For this reason, extended occupancy hours are included in the study. Technical data for the modelled building can be found in Table 1. The building has envelope insulation levels that are state of the art concerning energy-efficient buildings in Sweden. The models use ideal heaters and coolers, which do not take into account any efficiency of the systems, but since it is the energy demand and not energy supply that is investigated, which is not a problem.

**Table 1.** Technical data of the two models.

Location Data				
	Malmö (Sweden)		Linköping (Sweden)	
			Luleå (Sweden)	
Longitude	13.37 E		15.53 E	
Latitude	55.52 N		58.4 N	
Annual mean outdoor temperature	8.2 °C		6.6 °C	
Winter outdoor design temperature	−11.9 °C		−16.4 °C	
Daylight hours during summer solstice	17 h 31 min		18 h 19 min	
Daylight hours during winter solstice	7 h 2 min		6 h 20 min	
Building				
	Angled Façade		Straight Façade	
Model floor area	2308 m <sup>2</sup>		2308 m <sup>2</sup>	
Model volume	7155 m <sup>3</sup>		7154 m <sup>3</sup>	
Model ground area	585.1 m <sup>2</sup>		585 m <sup>2</sup>	
Model envelope area	2647.2 m <sup>2</sup>		2422.7 m <sup>2</sup>	
Window/envelope	19.0%		20.8%	
Average <i>U</i> -value	0.22 W/(m <sup>2</sup> × K)		0.22 W/(m <sup>2</sup> × K)	
Number of floors	4		4	
Building heat loss coefficient	592.33 W/K		526.5 W/K	
Air tightness	0.3 L/(s ext. surf.) @50 Pa		0.3 L/(s ext. surf.) @50 Pa	
Building Envelope				
	Angled Façade		Straight Façade	
	Area (m <sup>2</sup> )	<i>U</i> (W/(m <sup>2</sup> × K))	Area (m <sup>2</sup> )	<i>U</i> (W/(m <sup>2</sup> × K))
Walls above ground	981.59	0.13	757.3	0.13
Roof	577.0	0.10	576.9	0.10
Slab on ground	585.1	0.12	585.0	0.12
Curtain wall total	503.4	0.36	503.4	0.36
Glazing of curtain wall	201.6	0.70	201.6	0.70
Closed part curtain wall	301.8	0.13	301.8	0.13
Thermal Bridges				
	Angled Façade		Straight Façade	
	<i>U</i> · <i>A</i> (W/K)	% of total transmission	<i>U</i> · <i>A</i> (W/K)	% of total transmission
Thermal bridges	158.08	26.7	124.2	23.6
Construction				
	Material	Thickness (m)	Material	Thickness (m)
External wall	Concrete	0.26	Light insulation	0.27
Slab on ground	Concrete	0.20	Light insulation	0.20
Roof	Concrete	0.20	Light insulation	0.35
Ventilation System				
Heat exchanger efficiency	0.8			
Supply air flow rate	1.3 L/(s × m <sup>2</sup> )			
Return air flow rate	1.3 L/(s × m <sup>2</sup> )			



### 3. Method

This study was based on Building Energy Simulation (BES), using the dynamic energy simulation software IDA-ICE version 4.8.1 (Indoor Climate and Energy), of a new office building which is planned in the city of Linköping, Sweden. It was done as a parametric study with five different variables to see how the variables affected the building's energy use. The following variables were investigated: Two different façade types, eight different internal heat gains, three different locations, the use of blinds that are activated when the sun hits the window or no blinds at all, and eight different orientations. Combining all the different variables created 768 different simulations, see Table 2.

**Table 2.** The variation of the variables used in the parametric study. Control Sun means that the blinds are activated when the sun hits the window.

Façade	Internal Heat Gains (kWh/(m <sup>2</sup> × Year))	Location	Window Shading	Orientation
Angled	32.3	Linköping	On with Control Sun	0°
Not angled	42.9	Luleå	Off	45°
	46.3	Malmö		90°
	50.9			135°
	61.3			180°
	65.0			225°
	67.7			270°
	86.2			315°

#### 3.1. Building Energy Simulation and Validation

When it comes to analyzing a building's energy performance, building energy simulation is often held as the best approach within the building industry [18]. It is widely used throughout building projects to estimate the energy use of the finished building. It is also used for the purpose of predicting the future indoor climate of buildings. The software used in this study was IDA-ICE v4.8.1 (Indoor Climate and Energy), which is a dynamic energy simulation software developed by EQUA. Since this study was performed at a detailed design stage, empirical validation was not possible. However, IDA-ICE has been validated according to CEN standards EN 15255-2007, 15265-2007 and 13791, as well as ASHRAE Standard 140-2004. It has also been validated with reliable results in many field and in-situ studies during the years since its release in 1998, both for office buildings as well as other buildings [19–26].

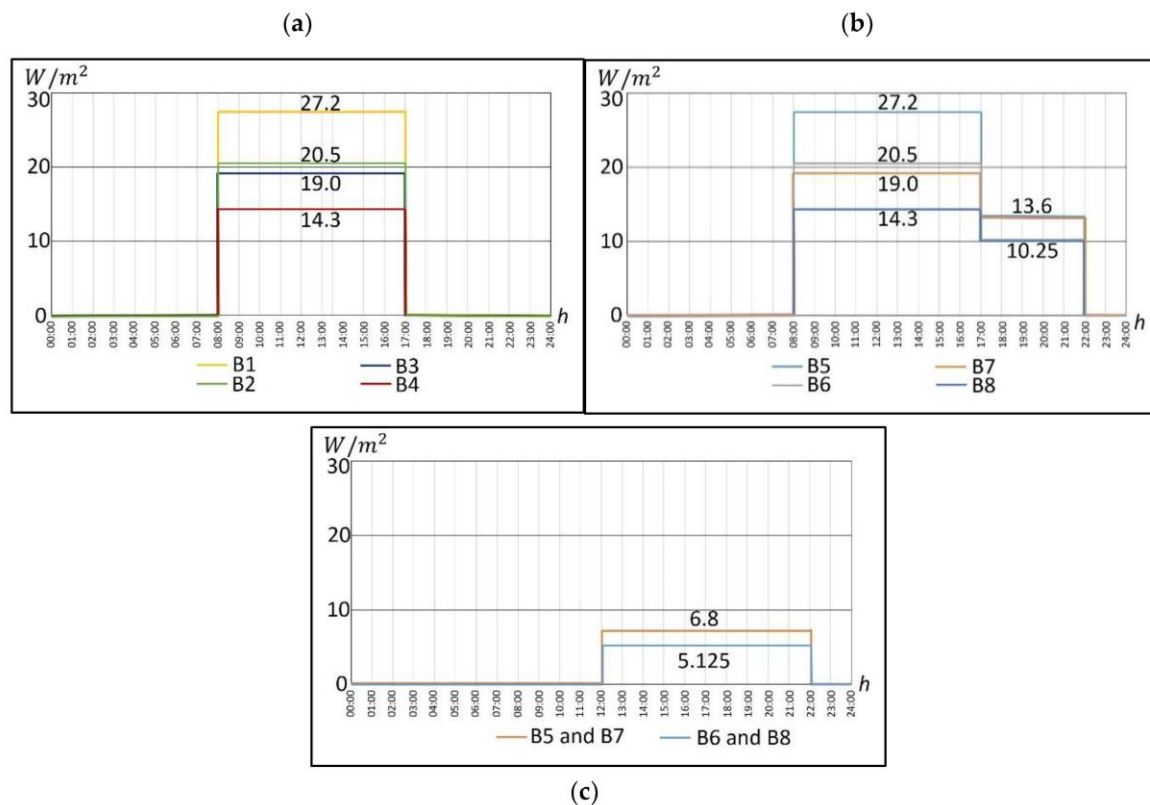
#### 3.2. The Façade

As previously described, the façade was designed to lower the cooling demand by angling the windows to the northeast and northwest instead of having a straight façade where the windows would be facing east and west. For this study, it was interesting to see how much this affected the energy use compared to if a “normal” straight façade had been used instead. For that reason, two models were created, one with the angled façade and one with a straight façade, and these two were named A1 and A2, respectively.

#### 3.3. Internal Gains

Four different types of occupancy schemes were used. The first is the Swedish building standard from Sveby [27] of 0.05 occupants/m<sup>2</sup>, who are present from 8–17, Monday–Friday, except for two weeks during the summer (vacation). This time schedule will be called “workdays”. The second one was created to represent a future scenario where more people work from home and to represent this an

occupancy of 0.035 occupants/m<sup>2</sup> present at workdays was used. The third and fourth schedule were made to represent an office that was used for longer periods of the day. Both schedules have 0.025 occupants/m<sup>2</sup> from 17–22 on workdays, and 0.0125 occupants/m<sup>2</sup> from 12–22 during weekends and vacation added to the 0.05 and 0.035 occupants/m<sup>2</sup> present on workdays in the first two schedules. This schedule for extra occupancy is called “extended” occupancy. Electricity was set according to two different scenarios, one according to Sveby’s standard annual value, which is 50 kWh/m<sup>2</sup> if the occupants are present 8–17 on workdays and will be called “standard” electricity use. The other schedule was set to 35 kWh/m<sup>2</sup> if the same occupancy as previously described was used, and will be called “low” electricity use. This was to represent a switch to more energy-efficient office equipment and/or to represent more people working from home. Since electricity use is connected to occupancy, electricity use and occupancy were combined to create eight different input values, named B1–B8, which were then used as input for the models (see Table 3). The schedules for internal heat gains can be seen in Figure 2. The ventilation system was set to operate with two different schedules, one schedule to match the workdays where it is on at maximum capacity from 7–19, Monday to Friday, and off during weekends and the vacation period. The second schedule was made to match the extended occupancy schedule where the ventilation system is on at a maximum capacity from 7–19 and at half speed from 19–23 during weekdays, and on at half speed from 11–23 during weekends and vacation period.



**Figure 2.** The total amount of internal heat gains from electricity use and occupancy combined for all the different cases of internal heat gains. (a) The schedule for workdays for cases B1, B2, B3 and B4, as described above, (b) the schedule for workdays for cases B1, B2, B3 and B4, as described above, and (c) the schedule for weekends, holidays and vacation period for cases B5, B6, B7 and B8. B1, B2, B3 and B4 have no internal heat gains during weekends and vacation.

**Table 3.** Different values for internal heat gains used in the models. Lighting and equipment does not include the electricity use of the ventilation system.

Name	Occupancy (Occupants/m <sup>2</sup> )	Electricity	Lighting and Equipment (kWh/m <sup>2</sup> × Year)	Heat from Occupants (kWh/m <sup>2</sup> × Year)	Total (kWh/m <sup>2</sup> × Year)
B1	0.05 workdays	Standard	50.0	11.3	61.3
B2	0.05 workdays	Low	35.0	11.3	46.3
B3	0.035 workdays	Standard	35.0	7.9	42.9
B4	0.035 workdays	Low	24.4	7.9	32.3
B5	0.05 workdays + extended	Standard	70.4	15.8	86.2
B6	0.05 workdays + extended	Low	49.2	15.8	65.0
B7	0.035 workdays + extended	Standard	55.3	12.4	67.7
B8	0.035 workdays + extended	Low	38.5	12.4	50.9

### 3.4. Location

Since Sweden is a country with greatly varying outdoor temperature and hours of daylight depending on latitude, it was interesting to see how this affected the buildings energy use. To investigate this, three different locations in Sweden were selected as inputs for the models. The three different locations used in this study were Linköping, Luleå, and Malmö. Location data can be found in Table 1.

### 3.5. Window Shading

Since the building was designed to use less cooling, it was of interest to see how a regular solar shading in the form of blinds would perform and therefore two scenarios were used: C1 was no blinds and C2 was with blinds activated, while there is sun coming through the window. C1, which is without any solar shading, had windows with a g-value of 0.5. C2 had the same type of windows and the blinds for this case had a g-value of 0.65, which together with the windows own a g-value that gives a g-value of 0.33

### 3.6. Orientation

The special façade design also made it interesting to investigate how different orientation affected energy use of the building. The two models were therefore rotated by 45° at a time creating eight different orientations for each case: N, NE, E, SE, S, SW, W, and NW. Figure 1 shows the reference surface for each model.

### 3.7. Indicators for Measuring Energy Efficiency/Performance

There are many indicators for assessing energy efficiency in the buildings and in Reference [3]; the authors used the following six indicators: kWh/m<sup>2</sup>, kWh/n<sub>persons</sub> (n<sub>person</sub> = number of occupants), kWh/hpers (hpers = sum of the number of hours that each building occupant spends in the building during the year in question), kWh/(m<sup>2</sup> × hpers), kWh/(m<sup>2</sup> × o) (o = average presence of the occupants during normal working hours 8–17 and normal workdays, where 0 ≤ o ≤ 1), and kWh/(m<sup>2</sup> × u).

Two of the above-mentioned indicators were used in this study. The first was kWh/m<sup>2</sup> and the second was kWh/(m<sup>2</sup> × hpers). The reason why these two were chosen is because kWh/m<sup>2</sup> is the most common indicator in the building sector and it is also the indicator that the Swedish National Board of Housing (Boverket) uses for setting requirements for energy use on buildings [28]. The second indicator, kWh/(m<sup>2</sup> × hpers) was chosen because it was interesting to see how the energy efficiency



was affected by changing the hours of use by either prolonging the number of hours the building was occupied or by changing the amount of people occupying the building. Of the indicators taking both space and occupancy into account, kWh/(m<sup>2</sup> × hpers) is the easiest to calculate according to Reference [3] and therefore the most likely to be incorporated into real-life building projects according to the authors of this article.

#### 4. Results and Analysis

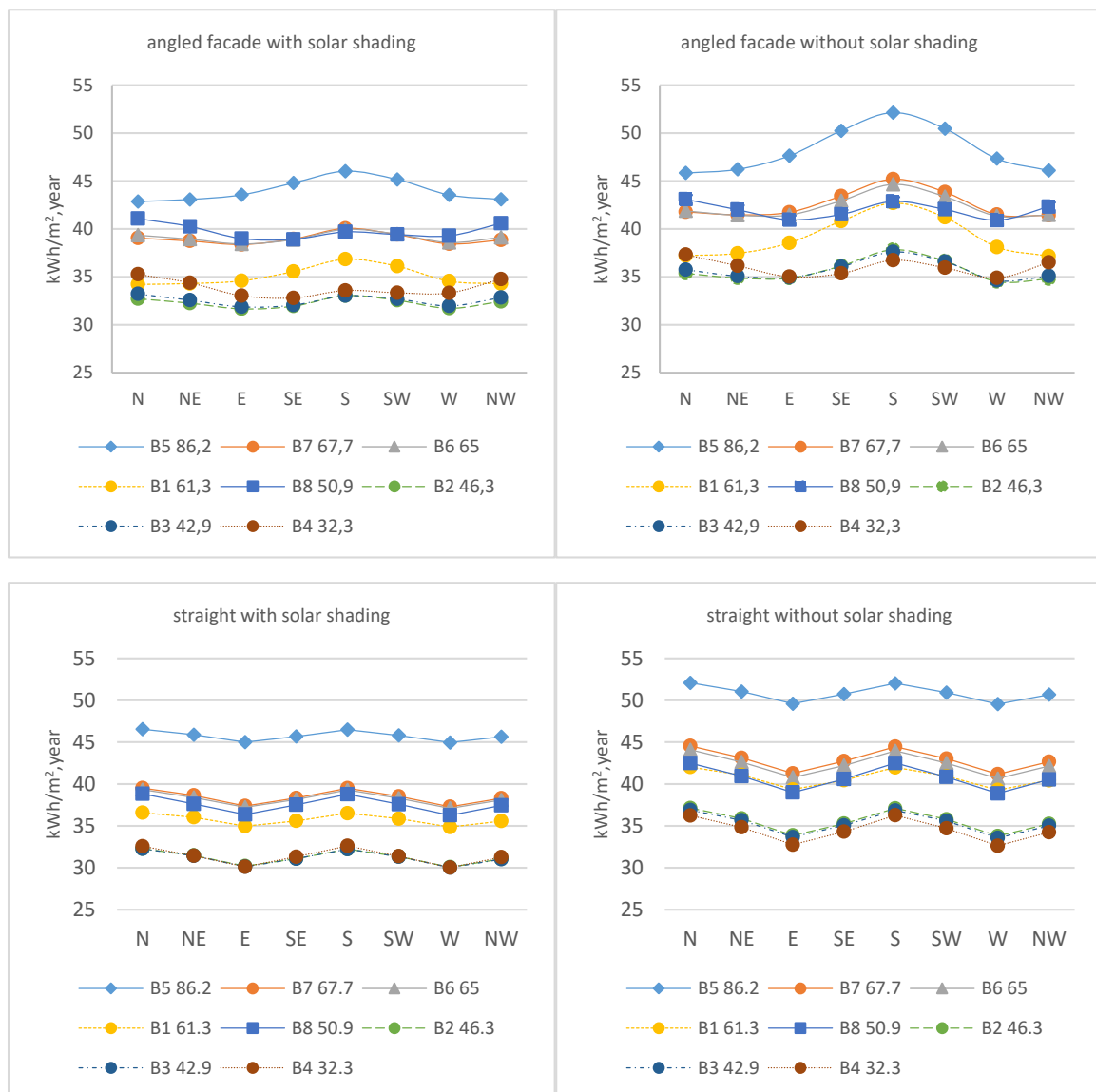
The results gathered from the BES-simulations performed in this study can be found in the following section. An analysis of the results is also included. The results are focused on energy use in the form of heating and cooling demand from the BES simulations of the different cases. They are compared against each other based on internal heat gains, location, façade type, orientation, and solar shading. Two different types of indicators are also used in this study, kWh/m<sup>2</sup>, and also kWh/(m<sup>2</sup> × hpers).

##### 4.1. Orientation

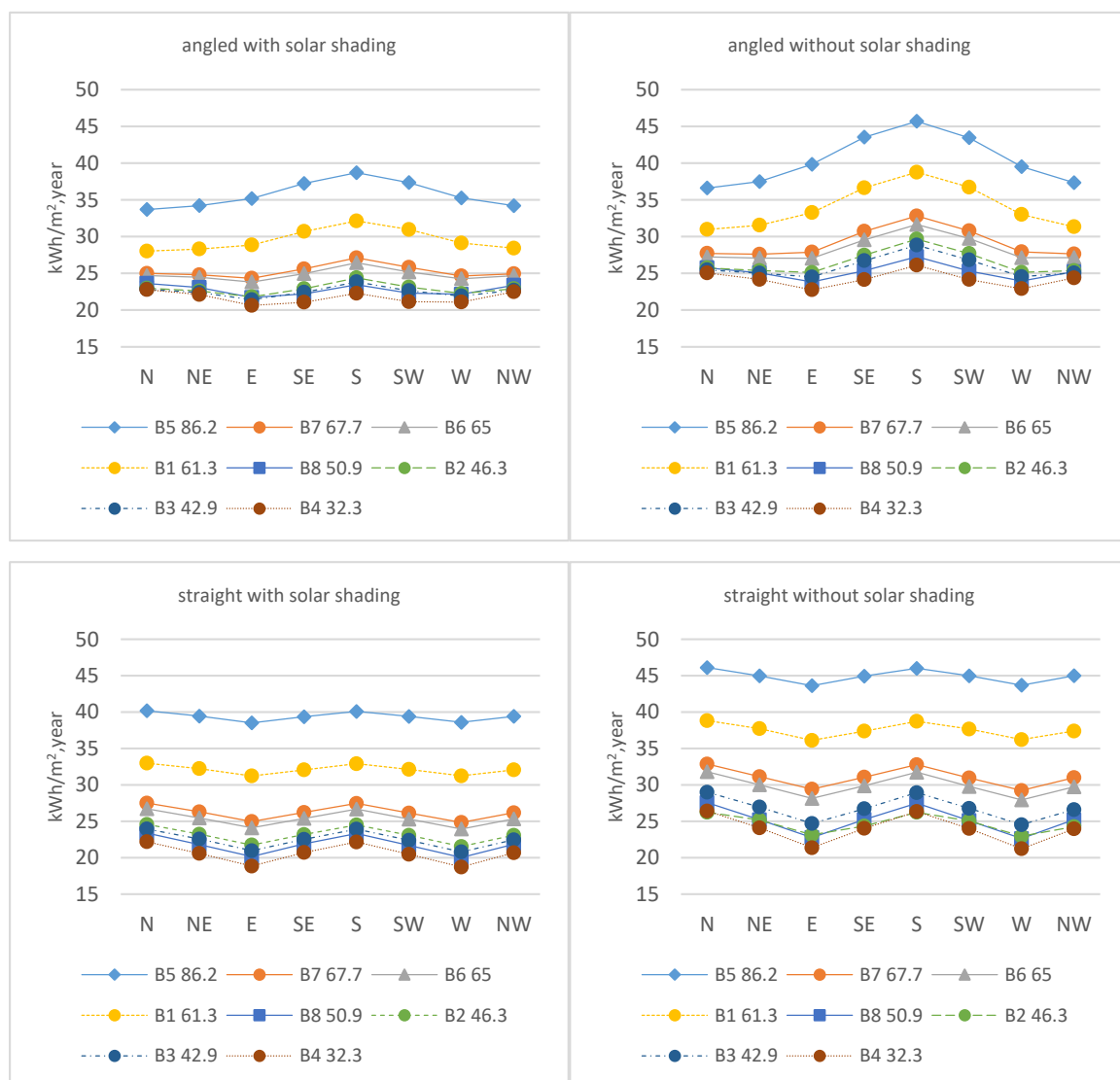
With a straight façade, one can observe in all three locations, that the orientation that gets the least total energy use has the reference surface pointing towards the east or west (windows facing north and south in both cases). The highest total energy use is having the reference surface directed to the north or south (see Figures 3–5).

In Luleå (see Figure 3), for B2, B3, B4, B6 and B8 without solar shading, it is best to point the reference surface towards the west (windows facing NW and SW). For B2, B3 and B6 with solar shading it is best to point it towards the east (windows facing NE and SE), and for B4 and B8 towards the south-east (windows facing south and east). The lowest energy use for B7 without solar shading is achieved when the reference surface is facing NW (windows facing N and W), and with solar shading it is when it is facing east (windows facing NE and SE). The highest energy use for B1, B2, B3, B5, B6, and B7 comes when the reference surface is facing south (windows facing SW and SE), both with and without solar shading. For B4 and B8, the highest energy use is when the reference surface is pointing north (windows facing NW and NE), both with and without solar shading.

For the city of Linköping (see Figure 4), the orientation of the reference surface that yields the highest total energy use is towards the south for all cases, except for B4, and B8 if an angled façade is used. For B4 and B8, the orientation with the highest total energy use is towards the north. The orientation that yields the lowest total energy use with an angled façade is towards the north for internal heat gains case B1 and B5 and towards the east for the rest of the cases, both with and without solar shading. When a straight façade is used, the orientation with the lowest total energy use for all cases of internal heat gains is towards the east and west, and the orientation with the highest total energy use is towards the north and south.

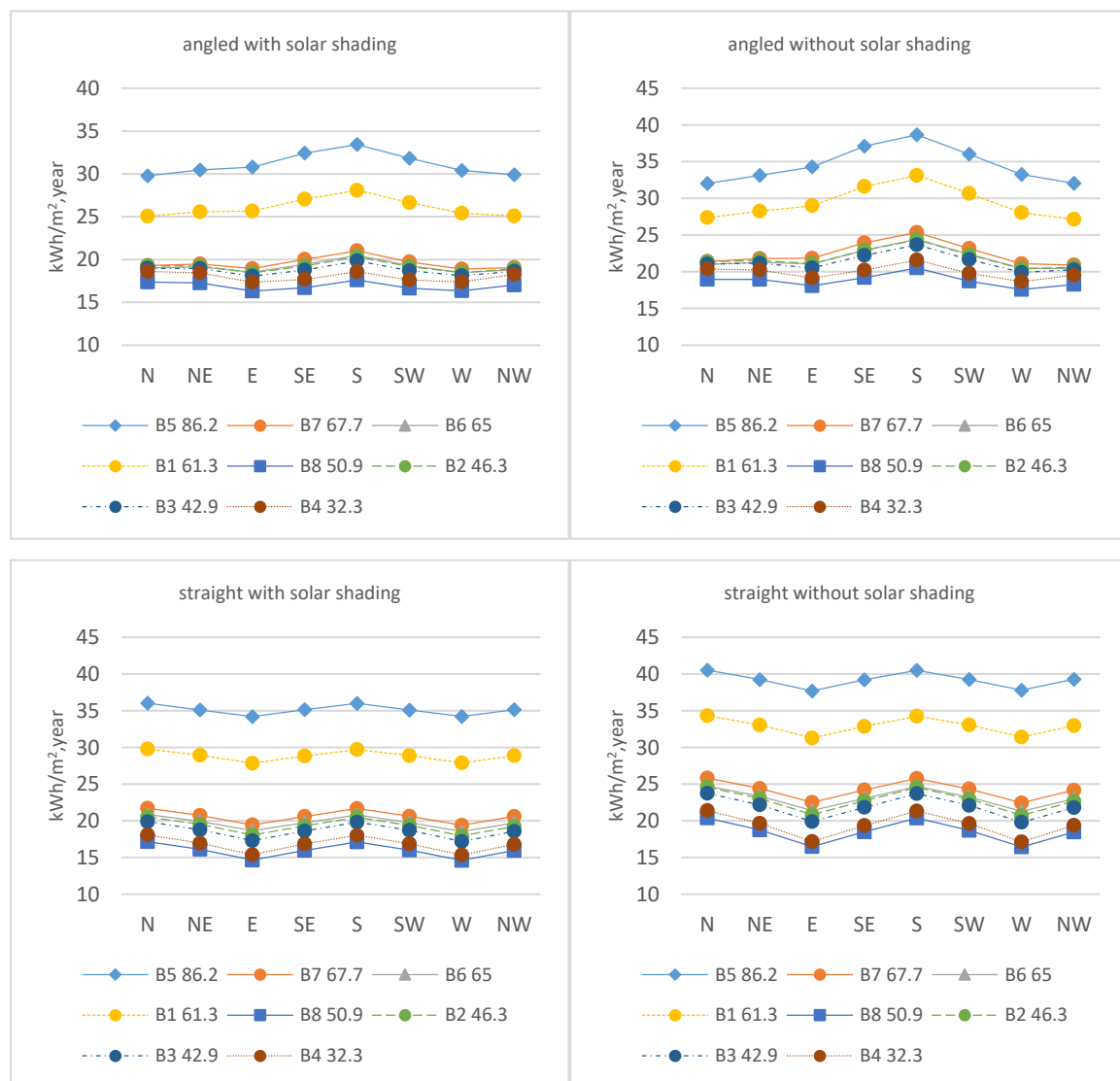


**Figure 3.** The total energy use for heating and cooling as a function of rotation of the office building in the city of Luleå. The eight different types of markers show results for each different amount of internal gain used in the simulations. The lines between the markers are only for ease of interpretation. The top left is with angled façade with solar shading, the top right is with angled facade without solar shading, the bottom left is with straight façade with solar shading and the bottom right is a straight façade without solar shading.



**Figure 4.** The total energy use for heating and cooling as a function of rotation of the office building in the city of Linköping. The eight different types of markers shows results for each different amount of internal gain used in the simulations. The lines between the markers are only for ease of interpretation. The top left is with angled façade with solar shading, the top right is with angled façade without solar shading, the bottom left is with straight façade with solar shading and the bottom right is a straight façade without solar shading.

In Malmö (see Figure 5), one can see that for the angled façade, the orientation that yields the highest total energy use has the reference surface pointing to the south in all cases of internal heat gains. The lowest total energy use for internal heat gains case B1 and B5 with solar shading is when the reference surface is facing north. For all other cases of internal heat gains with the use of solar shading we see that the orientation with the lowest total energy use is to the east. For an angled façade without solar shading with internal heat gains, B1, B5, and B7 have the lowest total energy use if the reference surface is facing north. The reference surface facing east has the lowest total energy use for other cases. The straight façade follows the same pattern as both Luleå and Linköping, where the highest total energy use is when the reference surface is pointing north or south and the lowest total energy use is when the reference surface points to the east or west.



**Figure 5.** The total energy use for heating and cooling as a function of rotation of the office building in the city of Malmö. The eight different types of markers show results for each different amount of internal gain used in the simulations. The lines between the markers are only for the ease of interpretation. The top left is an angled façade with solar shading, the top right has an angled façade without solar shading, the bottom left has a straight façade with solar shading and the bottom right has a straight façade without solar shading.

It seems that the higher the internal heat gains are, the more benefits can be seen with the angled façade, since in all three locations the lowest total energy use for internal heat gain cases B1 and B5, were achieved when the reference surface was facing north (windows facing north east and north west). One can see that the further south the building is located, the more the angled façade helps to keep down the total energy use. One can also observe that in all three locations, the lowest total energy use for cases with low internal heat gains, is achieved with a straight façade using solar shading and the reference surface is pointing east or west. This should be because the heat demand increases more than the cooling demand is decreased due to low internal heat gains and low solar heat gains.

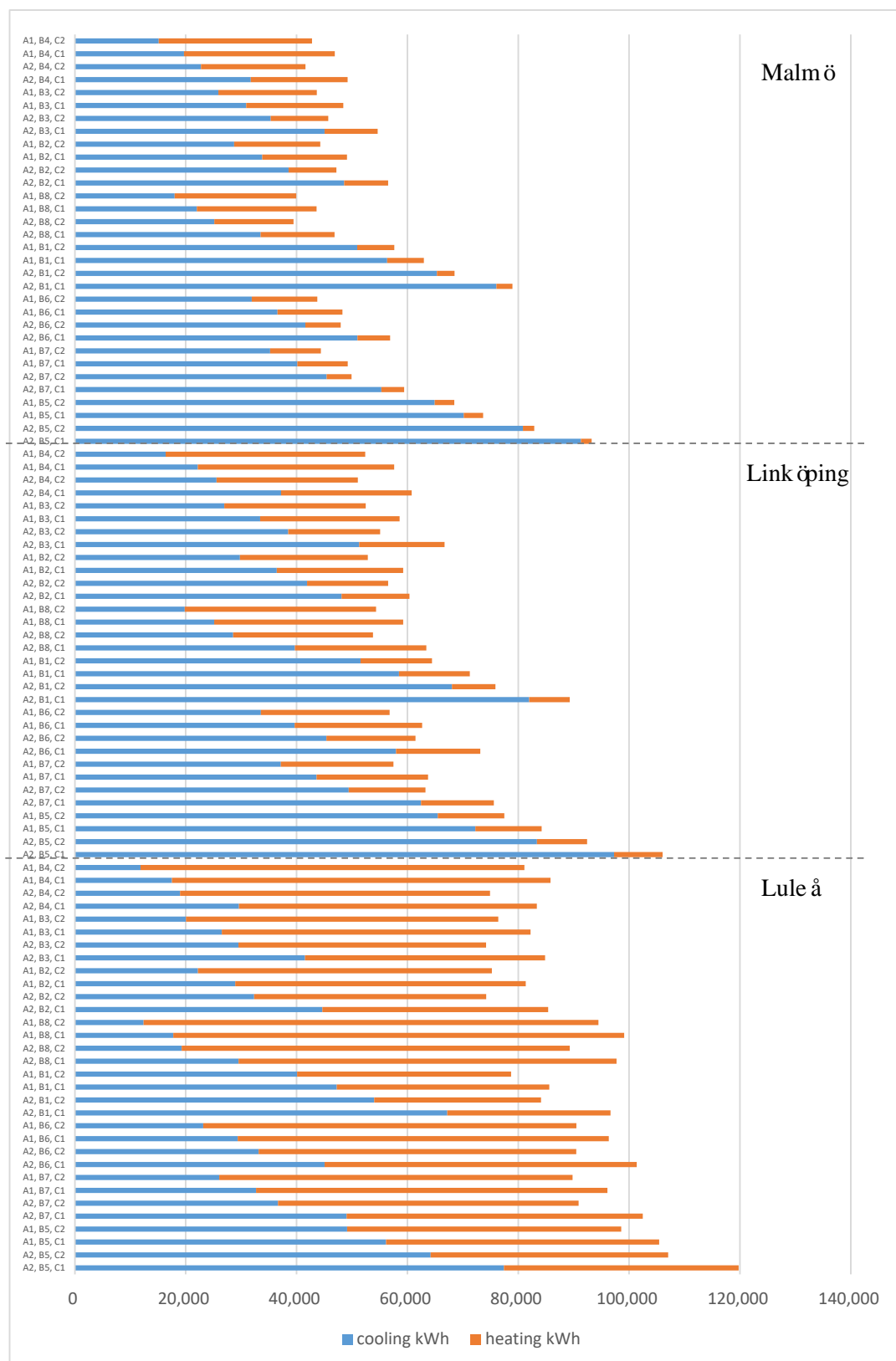
#### 4.2. Window Shading and Façade Design

As can be seen in Figures 3–5, the use of solar shading decreases the total amount of energy used in all cases. The solar shading decreases the cooling need for all cases and very slightly increases the heating need. The highest difference in heating can be seen in Linköping on a straight façade with internal heat gains B2, where the difference is an increase of 1.04 kWh/m<sup>2</sup> between not using solar shading and using solar shading. The cooling demand for the same case is, however, lowered by 2.72 kWh/m<sup>2</sup> when solar shading is used, thus giving an overall decrease in energy use of 1.68 kWh/m<sup>2</sup>. Comparing the results in Figure 6 between the two types of façade used in this study, one can see that the angled façade has slightly lower energy use in most cases, if both buildings are equipped with solar shading or if both are without solar shading. There are however a couple of cases where the use of a straight façade gives a lower total energy use, compared to the angled façade with the same solar shading installed, and these cases are the following; Luleå with internal heat gains B2, B3, B4 and B8, and Linköping and Malmö with internal heat gains B4 and B8. In the previously mentioned cases, the option with the lowest total energy use is a straight façade with solar shading and in all other cases, the use of angled façade together with solar shading give the lowest total energy use. B2, B3, B4, and B8 are the four cases with the lowest amount of internal heat gains and all cases where the straight façade is better, are cases where the heating need is higher than the cooling need. This means that, as soon as the heating need is higher than the cooling need, a straight façade might be better from an energy perspective. This is because the angled façade increases the heating need by not letting enough heat in through the windows during the colder parts of the year, as well as increasing the envelope area, thus giving higher heat transmission losses. In Figure 6, it can also be seen that, in most cases, it is better to install solar shading instead of having an angled façade without solar shading if total energy use is compared. The cases where this effect appears are the following: Luleå with internal heat gains B1, B2, B3, B4, B6, B7 and B8; Linköping with internal heat gains B2, B3, B4, B6, B7 and B8; and for Malmö with internal heat gains B2, B3, B4, B6 and B8. This is an interesting observation since the angled façade is much more expensive than a simple straight façade, when it comes to construction costs. As a result, in these cases, it is beneficial from both a cost and an energy use perspective to use the straight façade.

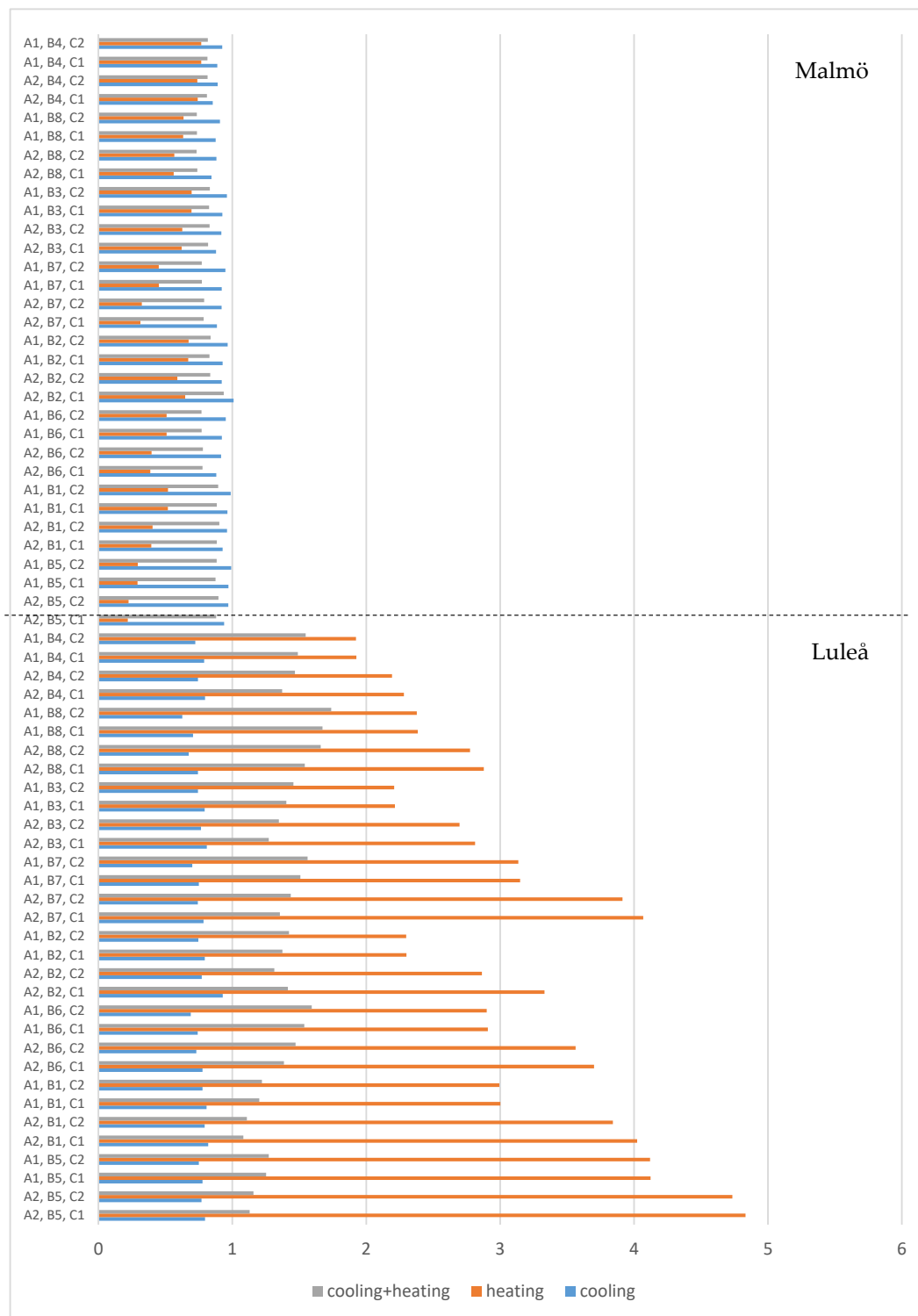
#### 4.3. Location

In order to illustrate how the different locations affect the buildings energy use, a comparison has been made with the buildings reference surface facing north in all cases which, means that the angled façade has windows facing towards northeast and northwest, and the building with straight façade has its windows facing east and west. In Figure 6, it can be seen that the further north the building is located, the higher the total energy use is. It can also be seen that in most cases in Luleå the heating demand is higher than the cooling demand and the difference increases as the internal heat gains become lower. For Linköping and Malmö it is the opposite, as there is a higher cooling demand than heating demand for most cases except for some cases with low internal heat gains. A comparison of heating, cooling and total energy use with Linköping as the reference case can be seen in Figure 7. Figure 7 shows that when cooling is the dominating form of energy use, location has little effect, but it has a large effect on heating demand. In Luleå, the heating demand is in most cases at least two times higher than in Linköping and in some cases more than four times as high, while the cooling demand is about 0.75 times the cooling demand of Linköping in almost all cases.





**Figure 6.** Total energy use, divided into heating and cooling, for all cases with the building facing north. Internal heat gains (B1–B8) are in the order from lowest to highest for each location. A1 is angled façade and A2 is straight façade. C1 is without blinds and C2 is with blinds.



**Figure 7.** Cooling, heating, and total energy (cooling + heating) demand for the building located in Luleå and Malmö compared to the building located in Linköping. Internal gains B1–B8 is ordered from lowest to highest. A1 is angled façade and A2 is straight façade. C1 is without blinds and C2 is with blinds.

#### 4.4. Internal Heat Gains

In this section, the effect of the different internal heat gains on heating, cooling and total energy use will be presented for each location. A couple of findings are similar no matter what the location

is. Even though B1 has lower total internal heat gains measured in kWh/year than B6 and B7 it still increases the buildings cooling demand so that it is higher than for B6 and B7 in all cases, as seen in Figure 6. The reason is because all internal heat gains in B1 are generated during daytime when the buildings also get free heat from the sun and outside temperatures are often a bit higher. B1 also has the highest internal heat gains measured in kW together with B5 during the daytime, which lead to a higher cooling demand. However, this also lowers the heating demand during the cold periods of the year so in Luleå the total energy use is still lower for B1 compared to B6 and B7, but in Linköping and Malmö where the cooling demand is the dominating factor, the effect is that the total energy use is higher for B1 than B6 and B7. It can also be seen in Figure 4 that, for the cases with internal heat gains B2, B3, and B4 (which are the three lowest) the total energy use almost stays the same if compared at each location. The differences are more or less only for the amount of cooling and heating demand. As the cooling demand decreases, the heating demand increases by almost the same amount. It seems that, when the internal heat gains become this low, the total energy use stabilizes. Finally, internal heat gains case B5 generates the highest total energy use.

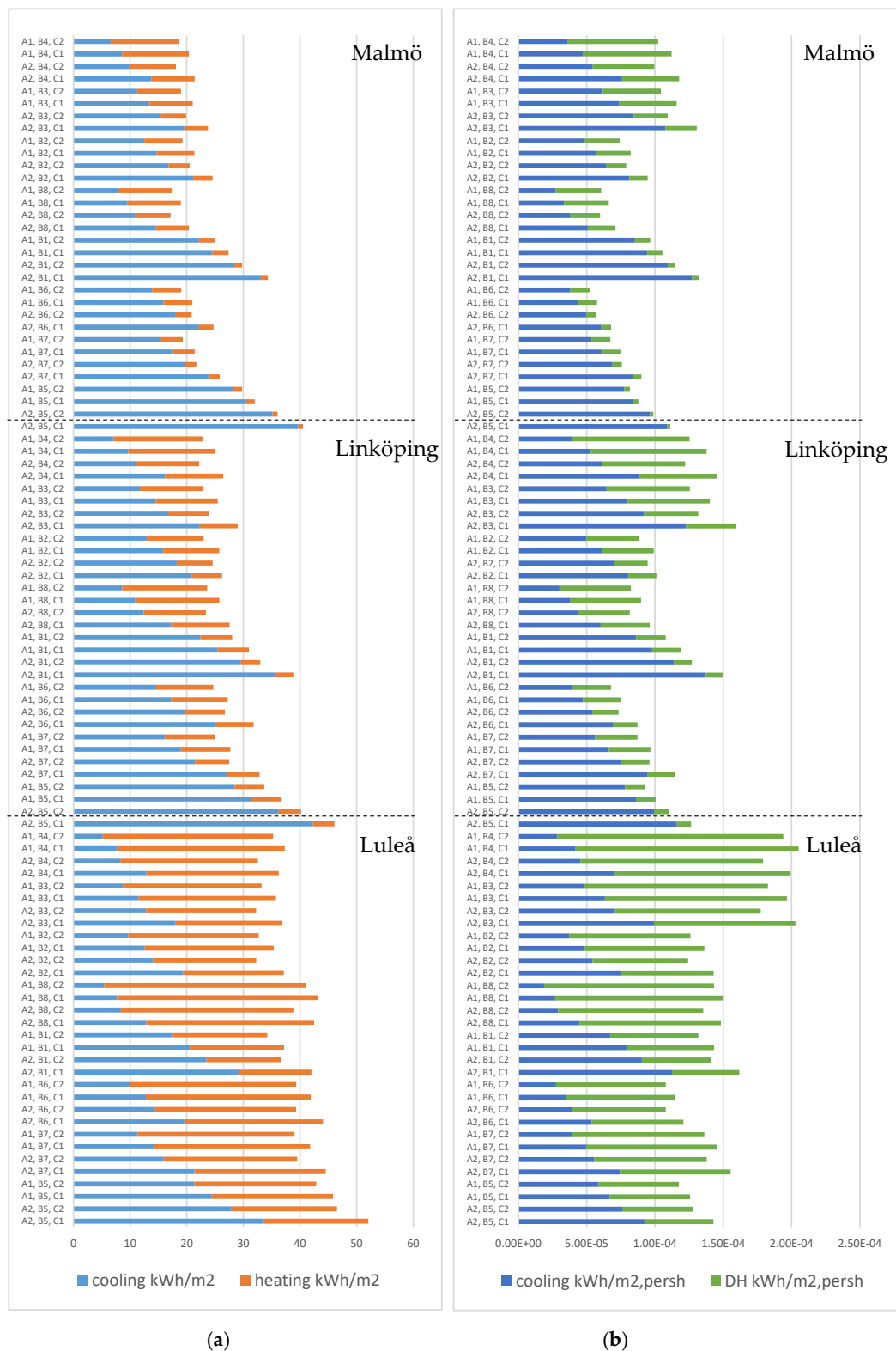
A couple of special observations for Luleå that can be seen in Figure 6 are that internal heat gains B4, and B8 generates almost the same amount of cooling demand but B8 has a higher heating demand. This seems to be because of losses from the ventilation system. In the models, the ventilation system was set to be on for all occupancy hours and since there are longer occupancy hours for B8 compared to B4, the ventilation system is also running more hours. One aspect that separates Luleå from the other two cities in this respect is that the higher internal heat gains in B8 are not enough to negate the losses from the ventilation system and therefore the cases with internal heat gains B8 having a higher heating demand than the cases with internal heat gains B4 in Luleå. The cases with B8 also have a higher total energy use than cases with internal heat gains B1. This effect only occurs in Luleå. A conclusion that can be drawn from this is that, in the northern part of Sweden, it could be a good idea to have a ventilation system that is presence activated with variable air volume (VAV) to minimize the heating losses if a building has low internal heat gains.

The differences between Linköping and Malmö are that Linköping has a slightly higher heating demand than Malmö, and Malmö has a slightly higher cooling demand. The total energy use is also a bit higher for all cases in Linköping, but the trends look almost the same for all different cases of internal heat gains.

#### 4.5. Indicators for Measuring Energy Efficiency

The most common indicator for energy efficiency in buildings in Sweden is kWh/m<sup>2</sup>. In Figure 8a, one can see that the trend is that the lower the internal heat gains are, the more energy efficient the building seems to be when using the indicator kWh/m<sup>2</sup>, with the exception of Luleå where one can see a very slight increase in the total energy demand for the lowest internal heat gains B4, and in Malmö where the lowest total energy demand is for internal heat gains B8, and for internal heat gains B1. However, Figure 8b highlights that if, kWh/(m<sup>2</sup> × hpers) is used as an indicator, the most energy-efficient building is with internal heat gains B6 for all locations. One can also see a different trend compared to using kWh/m<sup>2</sup> and that trend is that the lowest internal heat gains, B3 and B4, has the worst energy efficiency at all three locations together with B1 in Linköping and Malmö. These two cases of internal heat gains are the two with the lowest amount of occupancy, indicating that when this becomes a factor, low occupancy should be avoided. The best case, as previously mentioned, is B6, which has the highest occupancy hours together with B5, but with a low electricity use. It reveals that it is better to have a high occupancy together with energy-efficient electrical equipment, than low occupancy and low or high electricity use when occupancy hours are a factor. However, having high occupancy and high use from electrical equipment is not recommended when cooling need is the dominant factor, as it is in Linköping and Malmö, since the cases with internal heat gains B5 still have among the highest energy demand in these two cities. In Luleå though, where heating demand is the dominant factor, the cases with B5 have among the lowest total energy demand, and B1 is slightly

higher than B5, and almost equal to B2, B7 and B8. An additional note to this would be that it should always be desirable to have the lowest possible electricity use.



**Figure 8.** (a) Heating and cooling demand for all cases with indicator kWh/m<sup>2</sup>, year, (b) heating and cooling demand with indicator kWh/m<sup>2</sup>, hours of occupancy and year. Internal gains B1–B8 is ordered from the lowest to highest. A1 is angled façade and A2 is straight façade. C1 is without blinds and C2 is with blinds.

#### 4.6. Electricity Use of the Ventilation System

The models used in the study use two different schedules for the ventilation system, as described in Section 3.3. Using the first schedule called workdays give an electricity use of about 13,900 kWh/year or 6 kWh/m<sup>2</sup> and using the schedule for extended occupancy yields an electricity use of approximately 24,900 kWh/year or 10.7 kWh/m<sup>2</sup>. If this electricity use is included in the results of heating and cooling, it makes almost no difference to which occupancy and internal heat gains can be perceived as the most energy efficient. It makes a small difference in Malmö where the two cases with the lowest internal heat gains B3 and B4 are now perceived as the most energy efficient, if using kWh/m<sup>2</sup> as indicator, instead of B8, which is the case with the lowest energy demand if fan electricity is not included. If kWh/(m<sup>2</sup> × hpers) is used as an efficiency indicator, case B6 is still perceived as the most efficient case even if it includes electricity for the ventilation system. There are, however, some slight changes; case B2 can now be perceived as more energy efficient than case B8 in Malmö and Linköping, while Luleå stays the same.

### 5. Discussion

There is a large possibility that in the future company staff will begin to work more from home, as is already the trend [6–9], which has also been accelerated during the ongoing pandemic of COVID-19 [10]. This will not only affect internal heat gains in office buildings by less heat gain from the people themselves, but also from electrical equipment since the electricity use will decrease with decreasing number of occupants in the buildings. It might also be the case that there is still the same number of occupants or more, but the internal heat gains will go down due to more energy-efficient electrical equipment. It could be argued that, in the latter case, the energy supplied to the building will be used in a more efficient way, since more people are utilizing the supplied energy. In the former case though, fewer people are actually utilizing the energy, which could be considered less energy efficient. In this study, it has been shown that if a different indicator for energy efficiency is used, it is actually better to have more people in the building utilizing the energy even though the building uses more energy in absolute figures. Just as in References [2,6], the results from this study shows that if kWh/m<sup>2</sup> is used and when there is high occupancy and therefore also high space efficiency, the less energy efficient the building seems to be.

As can be seen in the results, Section 3.5, when changing the indicator for measuring energy-efficiency, the result of which internal heat gains gives the most energy efficient building also changes. This raises the question: Is kWh/m<sup>2</sup>, year, a good indicator for a building's energy efficiency? If a building is designed to house a low number of occupants, or a low number of occupants actually use the building when it is finished, it might have a low total energy use and look energy efficient if kWh/m<sup>2</sup>, year is used as an indicator. However, the energy that is supplied to the building is not really utilized by any people. It does show that the building has good technical specifications such as low U-values, and a well-designed ventilation and heating system, but it does not say anything about how the provided energy is utilized. If one also takes into consideration the occupancy hours, and the building is designed in a more space-efficient way, so that more occupants can use the building, it might have a higher total energy use, but the energy is utilized in a better, more efficient way. If an indicator that also takes occupancy hours into account is used, it should give architects and contractors an incentive to try and design buildings more space efficient instead of just staring blindly at the technical aspects. Thus, it should become a priority for the Swedish building sector to revise the standardized indicator for energy efficiency in buildings.

#### Orientation:

The orientation of the building is already set in the real project with the reference surface pointing to the north, and the façade is decided to be angled. However, it can be seen in all three studied locations that a straight façade with reference surface pointing to the east or west has lower energy use, at least for the cases with low internal heat gains. When using an angled façade one can also see that having the reference surface pointing to the east and west gives the lowest total energy demand for the



cases with low internal heat gains. This means that knowing the amount of internal heat gains is an important issue during the design phase of a building and it should therefore be of importance to try different orientations and façade designs within a building project before deciding on the final design. With a straight façade it seems that it is always preferable to have the reference surface pointing east or west. This means that the larger sides (the sides with windows) are pointing to the south and north. When studying the results more closely one can see that both the DH and DC demand are lower for this orientation. This is probably because during the winter the building can get more heat from the sun through the windows on the south side, and during the summer more heat can escape through the windows directed to the north. The highest total energy use belongs to the reference surface directed to the north or south when using a straight façade. When using an angled façade, it seems preferable to have the reference surface pointing east or west, when there are low internal heat gains, but when the internal heat gains get higher it is preferable to have the reference surface pointing north. This is probably because the angled façade prevents a lot of the heat from the sun to come into the building when the reference surface is pointing north. It can also be seen that for some of the cases with low internal heat gains in the city of Luleå it is actually better to have the reference surface of the angled façade facing south instead of north, which is probably due to the loss of heat from the sun when the reference surface is facing north.

#### Window shading and façade design:

The use of solar shading decreases the total energy demand in all cases. It slightly increases the heating demand and lowers the cooling demand. In Reference [15], they concluded that solar shading in offices facing north in many cases increase the energy demand, which might have been the case in this study, as well if simulations had been performed on the room-level instead of building-level. They also state that in offices facing south, a decrease in energy demand by 9% compared to not having any solar shading can be achieved with the right solar shading strategy. In some cases in the present study, one can see that a straight façade with solar shading is actually better than having an angled façade without solar shading. However, comparing these two options against each other will probably not be done in a real building project, since it is unlikely to construct an office building without any solar shading in the windows. The reason for this is not only that window shading helps to prevent some of the heat from coming into the building but it is also to prevent sunlight from disturbing people in the office. In all cases where a straight façade is better than an angled façade, the heating demand is higher than the cooling demand, leading to the conclusion that the angled façade as described above, increases the heating need by not letting enough heat in through the windows during the colder parts of the year.

#### Location:

According to the results, it seems that location has little effect on cooling demand but quite high effect on heating demand. Even though Luleå is located in the far north of Sweden, the building still has almost the same cooling demand as in the other two cities. This could be due to the number of daylight hours during summer in Luleå. In the north of Sweden, the sun almost never sets during the summer, which means that the building will be exposed to the sun for a longer period of the day than in the other two cities, which are located further south. However, during the winter the sun is almost never up, and the outside temperature is most often much colder in Luleå than in Linköping and Malmö, leading to a higher heating demand, and consequently a higher total energy demand.

#### Internal heat gains:

Occupancy behavior and consequently internal heat gains are among the hardest thing to predict for a new building, but as can be seen in the results of this study, among others [12,14,25], it has a huge effect on the total energy use. Different internal heat gains also affect the energy use differently depending on the location of the building. In Luleå, where heating demand is the dominating factor, higher internal heat gains can be better to get a lower total energy demand. However, in the south of Sweden where cooling is the dominating energy demand lower internal heat gains are better. Since internal heat gains have so much effect on a buildings energy demand it should get more attention in

the design phase, and deeper studies of this are needed within every building project. It should also be of interest for the property owner to get the occupants to use the building as intended. For instance, if the building is designed to facilitate 300 people that are there eight hours per day, there should be a continuous work from the property owner to plan and reach those values, so they do not end up with a building being used by 150 people for six hours per day. In many office buildings today, there is much less occupancy than was intended from the start, which can lead to huge energy performance gaps between predicted and actual energy use of a building. One should be clear that the standard schedules for occupancy and internal heat gains used in this study are made by Sveby, which is the standard used in building projects in Sweden. This was chosen since the study is made within a Swedish context. However, there are several other proposed schedules for occupancy and internal heat gains such as EN standards and ASHRAE, which, if used, could yield differences in the results.

One thing this article does not take into consideration, but which should be investigated in the future is how the cost of operation for the building changes with prolonged hours of use. Will it become a deficit, or can it be turned into an economic gain for the facility owner? This paper has focused on an office building and how energy-efficiency can be perceived there, but it does not take into consideration the broader spectra such as how we as a society can use buildings more efficiently, using the embodied energy within buildings more efficient. In a scenario where office buildings will be used for longer periods for various activities, less time will be spent in residential buildings, which leads to less energy use in our homes. Depending on which energy-efficiency indicator is used, residential buildings will either seem more or less energy-efficient. As the case is now during the COVID-19 pandemic, when a lot of people are working from home, it is the opposite, since a lot of people have turned their home into their office, probably resulting in use of more energy at home and a reduction of energy use in office buildings.

## 6. Conclusions

This study showed that internal heat gains have a significant impact on the total energy demand of an office building, and also that the chosen indicator for measuring energy efficiency plays a big part in which the level of occupancy, and subsequently internal heat gains, yields the most energy-efficient building. When using kWh/m<sup>2</sup> the most energy efficient-building, if looking at total energy use (heating and cooling) is one with low internal heat gains, and thus low occupancy. However, if one uses kWh/(m<sup>2</sup> × hpers), the most energy-efficient building is one with high occupancy but low electrical use. One could say that in the latter case, even though the total energy demand is higher than in the previous case, it is utilized in a more energy-efficient way, since it is utilized by a higher number of people. Therefore, revising the standardized indicator for energy efficiency in buildings in Sweden should be of priority in the building sector. The location of the building in Sweden seems to have little effect on the cooling demand, but more effect on the heating demand. Differences in internal heat gains, however, had a high effect on the cooling demand in all locations, where the biggest difference was 78% between the case with the lowest internal heat gains compared to the case with the highest internal heat gains in Malmö (the higher the internal heat gains, the higher the cooling need). When comparing heating demand between different cases of internal heat gains, the biggest difference in heating demand could also be seen in Malmö with 78% higher heating demand in one of the cases with low internal heat gains compared to one of the cases with high internal heat gains. If one instead looks at absolute values instead of percentage, it can be seen that the highest difference in cooling demand occurs in both Malmö and Linköping with 26 kWh/m<sup>2</sup>, higher for the cases with high internal heat gains compared to low internal heat gains. The biggest difference in absolute values of heating demand occurs in Luleå. The difference is 19 kWh/m<sup>2</sup>, year, higher for a case with low internal heat gains compared to one with high internal heat gains.

When it comes to façade design, it seems that it has more effect the further south the building is located, but in the more northern parts of Sweden it makes little difference. It is also revealed that, in many cases, it is better to have a traditional straight façade in the north than a façade where the

windows are angled away from the sun. This is because there is a bigger heating demand in the north than in the south.

A few recommendations for future office building projects in Sweden can be summarized as:

- One can achieve considerable results by just using a straight façade and regular solar shading (blinds).
- Using a façade that counters solar heat gains gives a better result the further south the building is located, while it is not beneficial in the northern parts of Sweden from an energy demand point of view.
- If an unconventional type of façade is considered, such as the saw-toothed façade in this study, always make predictions for the same building but with a conventional façade type to see if any benefit can be gained from using the unconventional façade. Otherwise, it may end up unnecessarily expensive with no real benefits.
- In-depth studies of potential internal heat gains should be done at the beginning of every new building project, so that a more area and energy-efficient building can be achieved.

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## References

1. IEA Statistics, Global Energy Data at Your Fingertips. Available online: <https://www.iea.org/statistics/> (accessed on 25 November 2019).
2. Martani, C.; Lee, D.; Robinson, P.; Britter, R.; Ratti, C. ENERNET: Studying the dynamic relationship between building occupancy and energy consumption. *Energy Build.* **2012**, *47*, 584–591. [CrossRef]
3. Huovila, A.; Tuominen, P.; Airaksinen, M. Effects of building occupancy on indicators of energy efficiency. *Energies* **2017**, *10*, 628. [CrossRef]
4. Menezes, A.C.; Cripps, A.; Bouchlaghem, D.; Buswell, R. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Appl. Energy* **2012**, *97*, 355–364. [CrossRef]
5. Neto, A.H.; Fiorelli, F.A.S. Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption. *Energy Build.* **2008**, *40*, 2169–2176. [CrossRef]
6. Dooley, K. New ways of working: Linking energy consumption to people. *REHVA J.* **2011**, 39–44. [CrossRef]
7. Hedberg, L.; Dreborg, K.H.; Finnveden, G.; Gullberg, A. *Room for the Future (Swedish Rum för framtiden)*; Totalförsvarets Forskningsinstitut: Stockholm, Sweden, 2003.
8. Ahmed, K.; Kurnitski, J.; Sormunen, P. Demand controlled ventilation indoor climate and energy performance in a high performance building with air flow rate controlled chilled beams. *Energy Build.* **2015**, *109*, 115–126. [CrossRef]
9. IVA-projektet Resurseffektiva lokaler i Sverige—Lokaldelning som norm; Kungliga Ingenjörsvetenskaps Akademien: Stockholm, Sweden, 2020.
10. Kramer, A.; Kramer, K.Z. The potential impact of the Covid-19 pandemic on occupational status, work from home, and occupational mobility. *J. Vocat. Behav.* **2020**, *119*, 1–4. [CrossRef] [PubMed]
11. Wolf, L. Office Space After Hours: 10 Creative Uses for Owners & Tenants. Available online: <https://www.vts.com/blog/office-space-after-hours-10-innovative-uses> (accessed on 18 March 2020).
12. Roetzel, A.; Tsangrassoulis, A.; Dietrich, U. Impact of building design and occupancy on office comfort and energy performance in different climates. *Build. Environ.* **2014**, *71*, 165–175. [CrossRef]

13. Manz, H.; Micallef, D.; Borg, S.P.; Buhagiar, V. A parametric building energy simulation case study on the potential and limitations of passive design in the Mediterranean climate of Malta. *Sustain. Build.* **2018**, *3*, 4. [CrossRef]
14. Bianco, F.; Degerfeld, M.; Ballarini, I.; De Luca, G.; Mamak, P. Sensitivity Analysis of the Thermal Energy Need of a Residential Building Assessed by means of the EN ISO 52016 Simplified Dynamic Method. *E3S Web. Conf.* **2020**, *197*, 02012. [CrossRef]
15. Grynning, S.; Time, B.; Matusiak, B. Solar shading control strategies in cold climates—Heating, cooling demand and daylight availability in office spaces. *Sol. Energy* **2014**, *107*, 182–194. [CrossRef]
16. Flodberg, K.; Blomsterberg, Å.; Dubois, M.C. Low-energy office buildings using existing technology: Simulations with low internal heat gains. *Int. J. Energy Environ. Eng.* **2012**, *3*, 1–9. [CrossRef]
17. Paone, A.; Bacher, J.P. The impact of building occupant behavior on energy efficiency and methods to influence it: A review of the state of the art. *Energies* **2018**, *11*, 953. [CrossRef]
18. Clarke, J. *Energy Simulation in Building Design*; Butterworth-Heinemann: Oxford, UK, 2007; ISBN 9781136406768. [CrossRef]
19. Sahlin, P.; Eriksson, L.; Grozman, P.; Johnsson, H.; Shapovalov, A.; Vuolle, M. Whole-building simulation with symbolic DAE equations and general purpose solvers. *Build. Environ.* **2004**, *39*, 949–958. [CrossRef]
20. Kropf, S.; Zweifel, G. Validation of the Building Simulation Program IDA-ICE According to CEN 13791 “Thermal Performance of Buildings—Calculation of Internal Temperatures of a Room in Summer Without Mechanical Cooling—General Criteria and Validation Procedures”. 2001. Available online: [http://mail.ssf.scout.se/iceuser/validation/ICE\\_vs\\_prEN%2013791.pdf](http://mail.ssf.scout.se/iceuser/validation/ICE_vs_prEN%2013791.pdf) (accessed on 10 November 2020).
21. Achermann, M. Validation of IDA ICE, Version 2.11.06 with IEA Task 12—Envelope BESTEST. 2000. Available online: [http://www.equaonline.com/iceuser/validation/old\\_stuff/BESTEST\\_Report.pdf](http://www.equaonline.com/iceuser/validation/old_stuff/BESTEST_Report.pdf) (accessed on 10 November 2020).
22. Englund, J.S.; Cehlin, M.; Akander, J.; Moshfegh, B. Measured and simulated energy use in a secondary school building in Sweden—a case study of validation, airing, and occupancy behaviour. *Energies* **2020**, *13*, 2325. [CrossRef]
23. La Fleur, L.; Moshfegh, B.; Rohdin, P. Measured and predicted energy use and indoor climate before and after a major renovation of an apartment building in Sweden. *Energy Build.* **2017**, *146*, 98–110. [CrossRef]
24. Liu, L.; Rohdin, P.; Moshfegh, B. Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden. *Energy Build.* **2015**, *102*, 32–44. [CrossRef]
25. Carlander, J.; Trygg, K.; Moshfegh, B. Integration of measurements and time diaries as complementary measures to improve resolution of BES. *Energies* **2019**, *12*, 2072. [CrossRef]
26. Eriksson, M.; Akander, J.; Moshfegh, B. Development and validation of energy signature method—Case study on a multi-family building in Sweden before and after deep renovation. *Energy Build.* **2020**, *210*, 109756. [CrossRef]
27. Sveby. *Brakarindata kontor: Version 1.1*; Sveby: Stockholm, Sweden, 2013.
28. Boverket. *Boverkets byggregler (2011:6)—föreskrifter och allmänna råd, BBR*; Boverket: Karlskrona, Sweden, 2019; Volume 1.

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