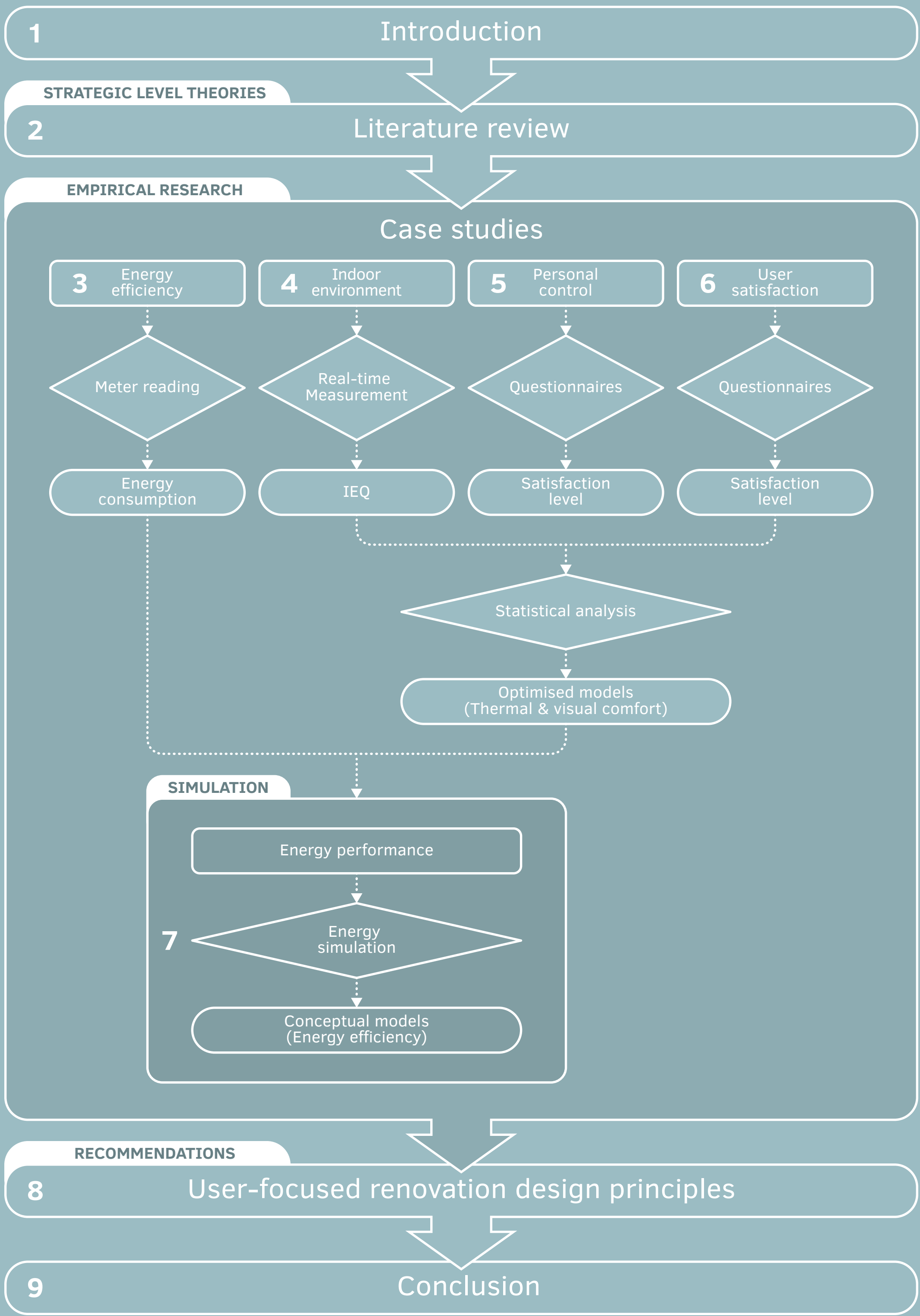
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7 The Impact of Design Parameters on Energy Demand for Office Renovation

Chapter 6 showed that the office layout and desk location were the most influential design factors for the thermal and visual comfort of users, and layout and orientation were most influential for psychological comfort in office buildings. Office design parameters were analysed to optimise user satisfaction in relation to indoor environmental and organisational quality in office buildings by showing predictable models. However, the predicted satisfaction models had not been tested in terms of energy performance. Therefore, this chapter evaluates the energy performance of the predicted models by computational assessment.

Section 7.2 explains the energy simulation scheme, model typologies, and simulation parameters. Section 7.3 presents the comparison of energy simulation results based on three design factors such as office layout, orientation and WWR. The results present the differences of the energy demand according to the alternative office typologies and contribution of design factors. The annual energy demand of 24 models are compared on the basis of different model typologies, and present the most energy-efficient typologies in section 7.4.

7.1 Introduction

In Europe, office buildings account for one quarter of the total non-residential floor area, which consume 280 kWh/m^2 per year (Jung et al., 2018). Renovating office buildings can have energy saving potential in the built environment. Despite the increasing attention to renovating existing offices, few studies have explored the relationship between alternative office designs and energy use. Offices are often designed to meet a functional and organisational requirement for workspaces. Numerous studies have analysed effective spatial layouts in an aspect of work performance (Haynes et al., 2017; Haynes, 2008; Rolfö et al., 2018). Chapter 6 analysed the impact of office design factors on user satisfaction. In the chapter, office layout is the most influential factor for user satisfaction with thermal and visual comfort, followed by orientation. In detail, people from cellular and flex offices tend to be highly satisfied with thermal and visual comfort and for satisfaction the open plan office proved to be the worst layout. In addition, workplaces oriented North-West are recommended for satisfaction, not South-West.

The predicted satisfaction models have not been analysed in terms of energy performance. According to Musau and Steemers (2008), the energy consumption of workspaces can be different according to their spatial planning since partition walls can affect daylight levels and airflows in workspaces, but it is not clear which design factors may cause higher energy demands. Therefore, it is necessary to test the energy performance of different office configurations. Optimal office configurations and envelop design may lead to significant improvements in energy savings.

Energy simulation is an important method that can help to test different models and test them before realisation (Heo et al., 2012). Lin et al. (2016) analysed façade configurations with the position of sunshades to minimise energy use, and Ochoa et al. (2012) investigated the optimal window-to-wall ratio (WWR) from a perspective of energy efficiency. They also considered visual comfort as a result of the façade design. This approach can be beneficial to quantify and validate the energy performance during the conceptual design stage. By using the DesignBuilder simulation tool, this paper examines the energy consumption of different workspace models for office renovations composed by design parameters such as orientation, layout, and WWR. The main research question answered in this study is which design combination of office layout, orientation, and WWR performs well to optimise energy-savings.

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7.2 Methodology

7.2.1 Design parameters and model typologies

The shape and size of the office considered are the same for all simulation cases. The simulation models are sited in The Hague in the Netherlands. 24 office models were created, representing a possible combination of design parameters (see TABLE 7.1).

TABLE 7.1 List of 24 energy simulation model variants

Number	Orientation	Office layout	WWR (%)
1	N.W/S.E	Cellular	30
2	N.W/S.E	Cellular	50
3	N.W/S.E	Cellular	80
4	N.W/S.E	Open	30
5	N.W/S.E	Open	50
6	N.W/S.E	Open	80
7	N.W/S.E	Combi	30
8	N.W/S.E	Combi	50
9	N.W/S.E	Combi	80
10	N.W/S.E	Flex	30
11	N.W/S.E	Flex	50
12	N.W/S.E	Flex	80
13	N.E/S.W	Cellular	30
14	N.E/S.W	Cellular	50
15	N.E/S.W	Cellular	80
16	N.E/S.W	Open	30
17	N.E/S.W	Open	50
18	N.E/S.W	Open	80
19	N.E/S.W	Combi	30
20	N.E/S.W	Combi	50
21	N.E/S.W	Combi	80
22	N.E/S.W	Flex	30
23	N.E/S.W	Flex	50
24	N.E/S.W	Flex	80

In the Netherlands, the standard structural grid of an office room is 5.4 m or 7.2 m wide (Remøy, 2010), and for the columns parallel to the façade a grid of 7.2 m is most common (Koornneef, 2012). Therefore, the simulation model in this study is a 14.4 m wide and 12.6 m deep office with a gross floor area of 163 m2 and a ceiling height of 3.3 m. The variations in the simulation model consider office layout, orientation, and WWR. As a fixed parameter, orientation is commonly not a part that can be influenced during a building renovation. Nonetheless, this study considered building orientation to include office buildings positioned in different ways.

FIG. 7.1 shows the types of office layout simulated in this study: cellular (Vos et al., 2000), open (Vos et al., 2000), combi (Danielsson & Bodin, 2008), and flex office (Danielsson & Bodin, 2008). The cellular office is composed of individual workspaces along the façade. The open-plan office accommodates more than 13 persons to share a space. The combi-office is an integrated type of single cells and open-plan office. Lastly, the flex office indicates that there are backup spaces, but individual workstations are not provided.

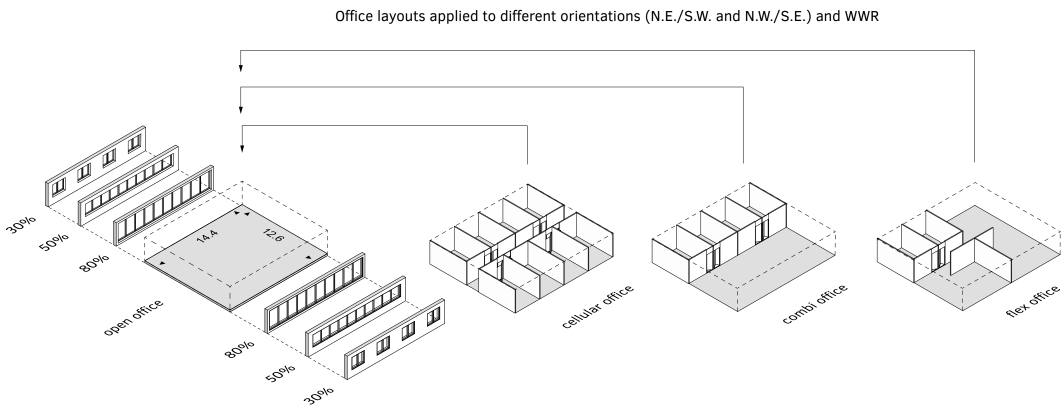

FIG. 7.1 Combination models of office design factors for the workspace energy simulation

The entire office building was not considered in the energy simulation. The support spaces, such as building core, pantry, and large conference or meeting rooms were excluded. The conceptual simulation model indicates workstations. Each layout has windows on two facades with opposite orientations such as North-West versus South-East, or North-East versus South-West. The orientations were chosen from existing office buildings in the Netherlands. Different window-to-wall ratios (30, 50, and 80%) were applied to the models.

7.2.2 Building parameters

Construction

The thermal transmittance values of construction elements used in energy calibration are summarised in TABLE 7.2. In the Netherlands, U-values (W/m2K) of different elements of office buildings must follow the Dutch building regulation Bouwbesluit2012 (2011). The floor and ceiling are treated as adiabatic.

TABLE 7.2 Thermal transmittance of building elements used as input values for simulations

		External wall	External floors	Internal floors	Flat roof	Windows	Sun-shading
Bouwbesluit2012 (2011) Netherlands	U-value	0.214	0.272	1.45	0.162	1.65	
	R_c value	4.5	6		3.5		
	g-value					0.7	0.2

HVAC system

The most dominant part of the energy consumption in commercial buildings is the heating, ventilation and air-conditioning (HVAC) system (Allouhi et al., 2015), which plays an important role in thermal comfort. Paoletti et al. (2017) stated that for high-energy efficient buildings, over 80% of mechanical ventilation systems include heat recovery, and around 30% of buildings use a heat pump to produce heating, cooling, and domestic hot water (DHW). Electricity is the most common energy source for thermal systems in Europe. Following these conditions, the simulation used variable air volume (VAV), air-cooled chilling, heat recovery (HR), outdoor reset for mixed mode ventilation types as options for the HVAC system. The heat pump was applied with a coefficient of performance (COP) of 2.0 for heating and cooling.

Operating settings for heating, cooling and ventilation

According to the NEN 15251 Guideline, an indoor temperature between 23-26°C is recommended in summer, and 20-24°C in winter. In order to qualify the recommended thermal condition, 22°C was chosen as the set-point temperature for heating, and 16°C as the set-back temperature. The cooling system operates at an indoor cooling set-point of 26°C. During non-occupied time, 28°C was applied as the cooling set-back temperature.

In the models, natural ventilation only operates when the indoor temperature is higher than the outdoor temperature, but not in wintertime. In order to use natural ventilation maximally, the set-point is 2°C lower than the cooling set-point and 2°C higher than the heating set-point, therefore reducing the energy use required for the active cooling system. For this reason, 24°C was chosen as the set-point for natural ventilation. Night ventilation was applied for the summer period, operating between 12.00 am to 6.00 am from June to August.

Lighting settings

The office zones require a illuminance of 500 lux (NEN 15251), and, require 1.8 W/m2, 100 lux of normalised power density based on EN 1246-1:2011. The lighting operating schedule was based on an occupancy schedule (see FIG. 7.2). For the illuminance, a LED type with linear control was used, which is a highly energy-efficient type, since the brightness output operates based on the relative illuminance of the workplace (daylight). A study of Tian and Su (2014) revealed that around 70% decrease in energy consumed by electric lighting was observed by the use of a dimming lighting control. Li and Lam (2001) found that the total energy use was mainly reduced by a dimmed lighting control and occupancy sensors. Lighting control is managed based on daylight illuminance and the occupancy schedule in the workplace. The lighting is off when a certain daylight illuminance is reached, and lighting was on when the daylight illuminance drops below the required illuminance value. The value of maximum allowable discomfort glare was set at 22 for offices (Suk et al., 2017). Internal sun-shading was applied to the workspace to minimise discomfort glare, with a transmission value (g-value) of 0.2.

Pandharipande and Caicedo (2011) reported that 5 m is a reasonable coverage range of lighting sensors in a typical workspace. For the calculation in this study, each room has a sensor, and the corridor has a sensor target of 200 lux for the cellular office layout. The distance between the lighting sensors and the number of sensors placed in an open-plan office was chosen by following the structured grid of a cellular office layout, placing 8 lighting sensors covering 3.6 m distance between the sensors. A shading device positioned outside is active when the solar radiation on the window exceeds the solar set-point of 150 W/m^2 (Raji et al., 2016; Park, 2003).

Occupancy and schedule

In order to reduce the energy consumption of office buildings, the optimal occupancy density is 0.03 persons/m2 (Kang et al., 2018). However, based on the Dutch NEN-1824 (2010) code, 0.1 persons/m2 occupancy density was considered for a cellular workspace and 0.09 persons/m2 for an open workspace including the circulation area. TABLE 7.3 shows the occupancy density and the number of people in each office type, 16 people for the cellular office and 15 people for the open, combi, and flex office layout. FIG. 7.2 shows the occupancy schedule and occupation percentage during weekdays. This data set was collected based on the working hours of case studies through field study. For the energy simulations, the use of a computer was also considered by following this occupancy schedule.

TABLE 7.3 Occupancy density and the number of people in each office layout

	Cellular	Open	Combi	Flex
Conditioned area (m2)	151.40	162.81	157.10	158.42
Occupant density (m2/ Person)	9.76	11.11	10.62	10.86
People	16	15	15	15

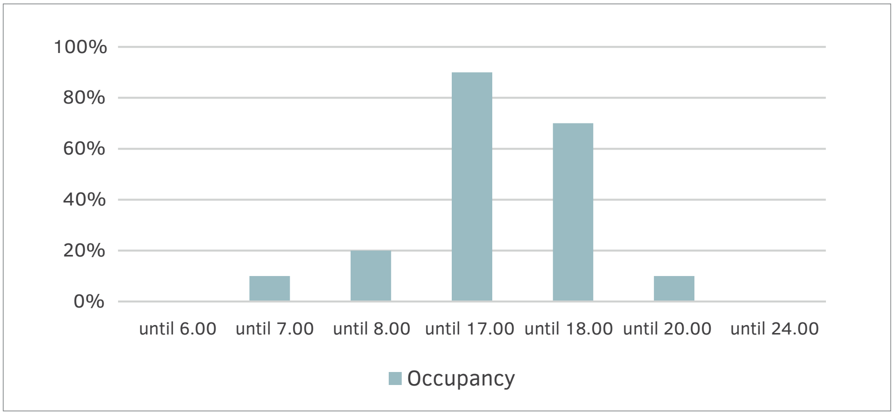

FIG. 7.2 Occupancy schedule

7.2.3 Simulation

Design Builder interface version 5.4, and 8.6 for EnergyPlus was used as the energy performance simulation tool. First, an office space was created as a prototype for each office layout. The values of occupancy schedule and density, HVAC, lighting types, temperature set-points, and U-values of building elements as fixed parameters were defined by literature (Allouhi et al., 2015; Bouwbesluit2012, 2011; CEN, 2007; Li & Lam, 2001) as given above. The values were applied to every model. Twenty-four models with different combinations of design parameters were tested to evaluate operating energy demands. The operating energy here indicates maintaining the indoor environment through heating, cooling, lighting and operating appliances (Cabeza et al., 2014).

7.3 Lighting sensor position

In order to validate the suggested positions of the lighting sensor, five different variants were simulated. FIG. 7.3 shows the results of simulation data based on the different number of lighting sensors and positions. First, an office space was divided into 3 and 2 zones parallel to the glazed façade, and 6 and 4 sensors were placed respectively. The energy demand of the two models was the same. It indicates that placing sensors in two rows is enough to cover the range of space. Next, the model was tested to identify how many sensors need to be placed in a row. Lighting sensors were placed every 1.8 m, 2.4 m, 3.6 m, 4.8 m, and 7.2 m perpendicular to the long facades with windows. The energy demand between lighting sensors placed every 1.8 m and 2.4 m was negligible by only 3% of energy reduction of lighting. Interestingly, there was a large decrease in energy demand between lighting placed at a 2.4 m distance and at 3.6 m. Positioning lighting sensors every 3.6 m could reduce 6% of the lighting energy demand and 5% of the total energy demand. From a structural perspective, 3.6 m matches the structural grid for beam spans in office buildings. Consequently, 4 zones (8 lighting sensors) with 3.6 m of sensor distance was selected for further simulation.

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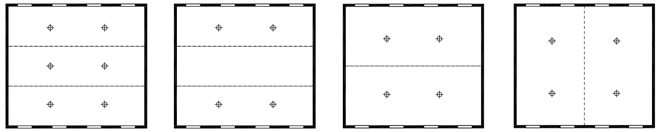
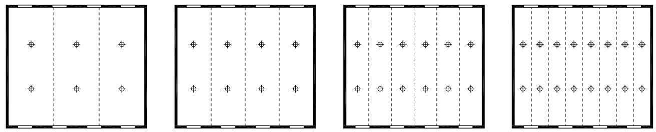
	3 zones, 6 sensors	3 zones, 4sensors	2 zones, 4 sensors	2 zones (7.2m)
				
Total (kWh/m^2/year)	41.74	41.74	39.36	39.41
Lighting	14.70	14.70	13.67	15.42
Heating	4.27	4.27	4.99	4.96
Cooling	10.90	10.90	8.82	7.16
Others	11.87	11.87	11.87	11.87
	3 zones (4.8m)	4 zones (3.6m)	6 zones (2.4m)	8 zones (1.8m)
				
	41.94	43.71	45.91	45.96
	16.94	17.88	18.96	19.66
	3.89	3.31	2.75	2.75
	9.23	10.65	12.32	11.67
	11.87	11.87	11.87	11.87

FIG. 7.3 Simulation of the lighting sensor positions for open plan

7.4 Energy performance based on energy criteria

Annual energy simulations were performed for 24 models (i.e., combination of 4 office layouts, 3 WWRs, and 4 window orientations). The simulation calculated the energy used for heating, cooling, lighting, and equipment (e.g., ICT equipment), and the total energy demand per square meter per year of workspace. The hourly weather data of the Rotterdam – The Hague region were obtained from OneBuilding (http://climate.onebuilding.org). FIG. 7.4 shows the division of energy demand based on heating, cooling, lighting and others. In general, lighting was responsible for 31% of the total annual energy demand per square meter, 22% for heating, 19% for cooling, and 28% for ICT equipment.

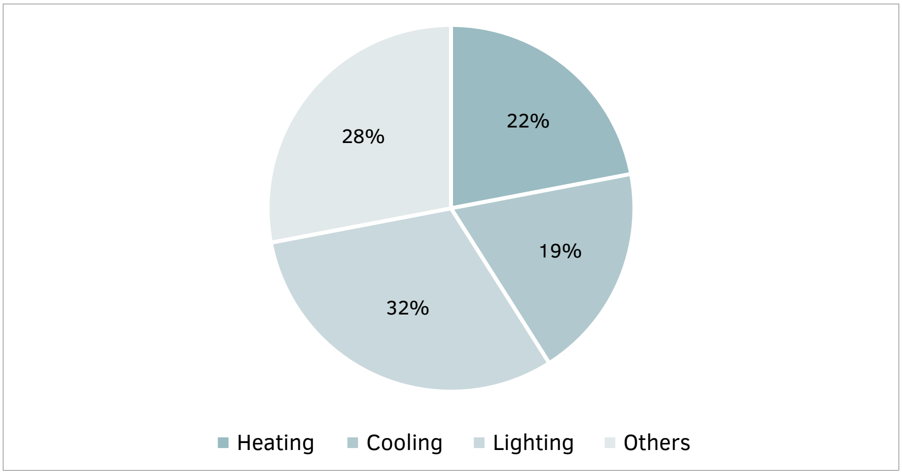


FIG. 7.4 Ratio of energy demands based on heating, cooling, lighting and others for all 24 models

7.5 Results of energy simulation models

TABLE 7.4 shows the annual energy demand in a workspace according to the combination of different office design parameters. The typologies consisted of 24 alternative models that encompassed a combination of different design parameters. FIG. 7.5 further elaborates the annual energy demand per square meter and the distribution of the demand according to each energy demand category in different variants. The dotted lines in FIG. 7.5 indicate the average of the energy demand in each energy category.

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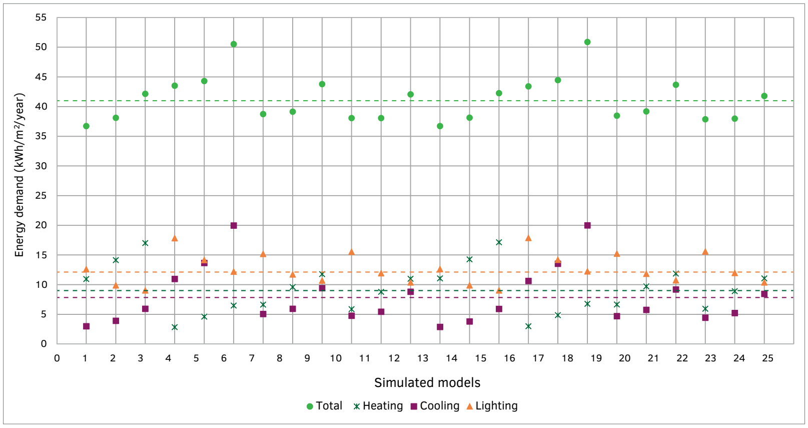
TABLE 7.4 Annual energy demand in an office space according to different office typologies

Number	Orientation	Office layout	WWR (%)	Total (kwh/m2/year)	Heating	Cooling	Lighting	Others
1	N.W/S.E	Cellular	30	36.71	10.95	3.00	12.61	10.16
2	N.W/S.E	Cellular	50	38.12	14.14	3.93	9.90	10.16
3	N.W/S.E	Cellular	80	42.16	17.00	5.94	9.05	10.16
4	N.W/S.E	Open	30	43.52	2.85	10.96	17.84	11.87
5	N.W/S.E	Open	50	44.31	4.61	13.67	14.16	11.87
6	N.W/S.E	Open	80	50.53	6.48	19.97	12.20	11.87
7	N.W/S.E	Combi	30	38.75	6.63	5.06	15.18	11.87
8	N.W/S.E	Combi	50	39.15	9.60	5.93	11.74	11.87
9	N.W/S.E	Combi	80	43.78	11.77	9.43	10.71	11.87
10	N.W/S.E	Flex	30	38.07	5.87	4.77	15.55	11.87
11	N.W/S.E	Flex	50	38.06	8.80	5.45	11.93	11.87
12	N.W/S.E	Flex	80	42.06	11.00	8.81	10.38	11.87
13	N.E/S.W	Cellular	30	36.73	11.07	2.88	12.63	10.16
14	N.E/S.W	Cellular	50	38.13	14.26	3.81	9.90	10.16
15	N.E/S.W	Cellular	80	42.26	17.15	5.91	9.04	10.16
16	N.E/S.W	Open	30	43.40	3.01	10.63	17.88	11.87
17	N.E/S.W	Open	50	44.46	4.86	13.52	14.21	11.87
18	N.E/S.W	Open	80	50.88	6.77	19.99	12.24	11.87
19	N.E/S.W	Combi	30	38.48	6.66	4.70	15.24	11.87
20	N.E/S.W	Combi	50	39.19	9.72	5.76	11.84	11.87
21	N.E/S.W	Combi	80	43.67	11.86	9.19	10.75	11.87
22	N.E/S.W	Flex	30	37.87	5.95	4.44	15.60	11.87
23	N.E/S.W	Flex	50	37.98	8.91	5.22	11.98	11.87
24	N.E/S.W	Flex	80	41.79	11.06	8.46	10.39	11.87



Number	Orientation	Office layout	WWR (%)
1	N.W/S.E	Cellular	30
2	N.W/S.E	Cellular	50
3	N.W/S.E	Cellular	80
4	N.W/S.E	Open	30
5	N.W/S.E	Open	50
6	N.W/S.E	Open	80
7	N.W/S.E	Combi	30
8	N.W/S.E	Combi	50
9	N.W/S.E	Combi	80
10	N.W/S.E	Flex	30
11	N.W/S.E	Flex	50
12	N.W/S.E	Flex	80
13	N.E/S.W	Cellular	30
14	N.E/S.W	Cellular	50
15	N.E/S.W	Cellular	80
16	N.E/S.W	Open	30
17	N.E/S.W	Open	50
18	N.E/S.W	Open	80
19	N.E/S.W	Combi	30
20	N.E/S.W	Combi	50
21	N.E/S.W	Combi	80
22	N.E/S.W	Flex	30
23	N.E/S.W	Flex	50
24	N.E/S.W	Flex	80

FIG. 7.5 Comparisons of energy demand between 24 models

Total energy demand

Regardless of orientations, the flex office model with a WWR of 50% consumed less energy in all energy criteria than on average. Open-plan offices and workspaces with a WWR of 80% required the greatest amount of total annual energy use, while cellular offices showed the smallest total energy use. The highest total energy demand model (N.E/S.W, open, 80%) in total required around 38% more energy than the lowest one (N.W/S.E, cellular, 30%). However, the lowest total energy demand models were not optimal energy-efficient ones for all categories. The cellular, combi, and flex office with a WWR of 30% and 50% required a relatively lower total annual energy demand than on average. In contrast, the open-plan office showed the highest energy demand.

Heating energy demand

The open-plan office with a WWR of 30% was the optimal layout that can reduce a large amount of heating energy, followed by the open-plan office with a WWR of 50% and the flex office with 30%. In contrast, cellular office types showed the worst energy efficiency for space heating. The reason can be that a smaller WWR contributes to reduced heat loss, and each room needs to be heated separately to reach a certain temperature; therefore, the cellular office layout consumed more energy.

Cooling energy demand

The cellular office with a WWR of 30% was the most efficient office type for space cooling. The flex office required less cooling energy than the combi office. In contrast, the open-plan office with a WWR of 80% had the highest cooling energy demand. Mixed-mode ventilation was applied to the simulation models. For that reason, having more cellular rooms could cool down the individual workspaces quicker than a large open-plan area, resulting in a lower cooling energy demand.

Lighting energy demand

Overall, a larger window-to-wall ratio required less energy for lighting than smaller ones. When the WWR increased from 30% to 50%, around lighting energy demand decreased by 20%, and if the WWR increased from 50% to 80%, the lighting energy demand decreased by around 10%. The cellular office with a WWR of 80% had the lowest lighting energy demand. The flex office with a WWR of 80% was the second optimal model for a low lighting energy demand. In contrast, the open-plan office with a WWR of 30% required almost twice more energy for lighting than the optimal model. Flex and combi offices with a WWR of 30% also required more energy for lighting than average.

7.6 Energy demands based on design factors

In spite of the energy distribution ratio shown in Figure 7.4, the energy category majorly responsible for the total energy demand was different according to the design factors. Although the total energy demand was quite similar among cellular, combi, and flex offices, except for the open-plan office, the flex office layout was shown as the most energy-efficient layout for the total energy consumption, as shown in FIG. 7.6.

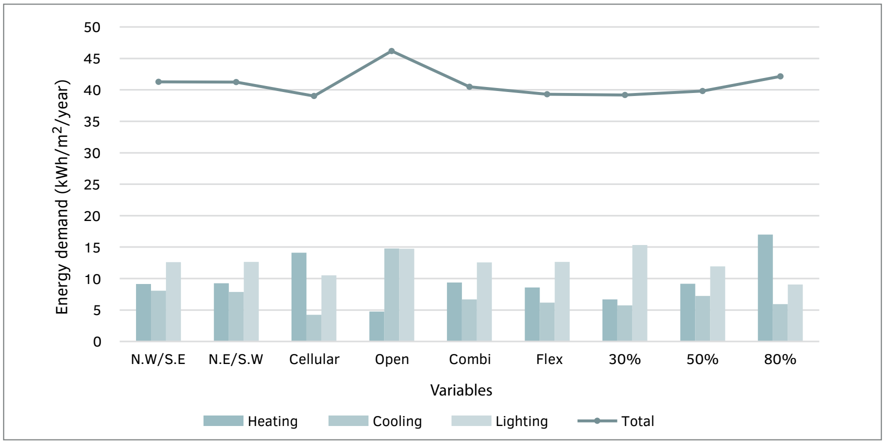


FIG. 7.6 Mean values of annual energy demand based on orientations, office layouts, and WWR

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7.6.1 Office layouts and energy demand

FIG. 7.7 shows the energy demand according to the office layout. There was a significant difference between cellular and open-plan offices. The cellular office required the largest amount of energy for space heating, accounting for 36% of total energy demand, and the smallest for cooling. Moreover, due to a smaller lighting illuminance needed for corridors, the cellular office required relatively less energy for lighting than other types. In contrast, the open-plan office required significantly less energy for cooling, and more for heating and lighting. The heating and cooling demands accounted for a similar percentage in combi and flex office types. Remarkably, the lighting was majorly responsible for the total energy demand, except for the cellular office. A trend shown in FIG. 7.7 is that when the heating demand increases, the cooling and lighting demand decrease.

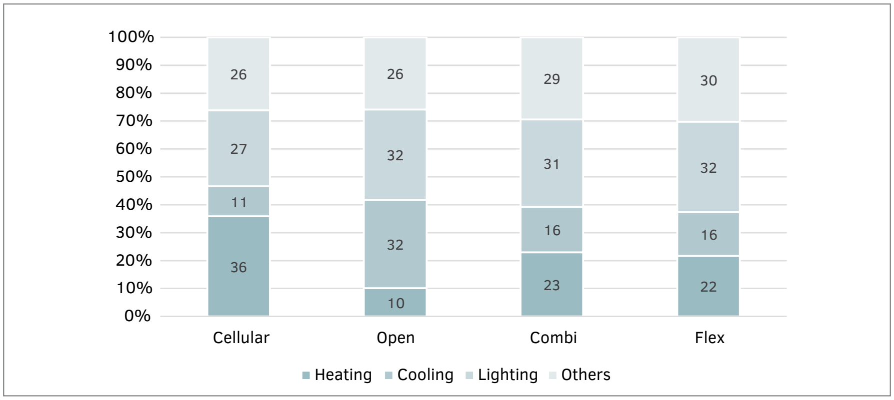

FIG. 7.7 The energy categories based on spatial layouts

7.6.2 Orientations and energy demand

FIG. 7.8 shows the ratio of energy demands based on the orientation. Proportion-wise, there was no difference in energy demand for each category between N.W/S.E-oriented models and N.E/S.W-oriented ones. It is noteworthy to mention that there was no significant difference between the heating and cooling energy demand according to different orientations. It is assumed that the cause of this result is that the energy demand was compensated by solar gains or sun-shading from the opposite orientation. Therefore, the energy demand was barely influenced by the orientation.

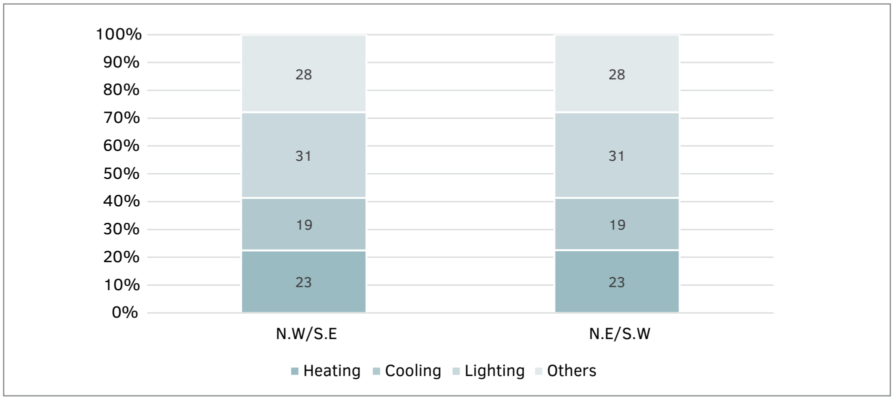

FIG. 7.8 The energy categories based on orientations

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7.6.3 Window-to-wall ratio and energy demand

The energy demand of models classified by the WWR shows a significant difference in total, heating, cooling and lighting energy demand (see FIG. 7.9). Overall, a larger WWR required more heating energy. When the heating energy demand increased, the cooling demand also increased within the same office layout, while lighting energy demand decreased. There is a positive linear relationship between heating and cooling energy demand on the one hand and WWR on the other. The energy demand for lighting showed a negative linear relationship. The heating and cooling energy demand gradually increased when the WWR increased from 30% to 80%. In addition, there was a drastic drop of lighting energy demand in case the WWR increased from 30% to 50%.

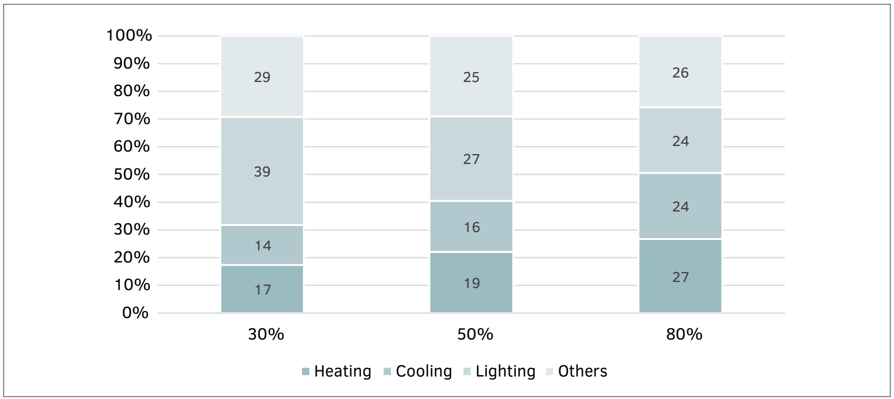

FIG. 7.9 The ratio of energy categories based on window-to-wall ratio

7.7 Discussion

7.7.1 Impact of design factors on energy performance studies

The research presented shows that the spatial layout and glazing area are significant design factors in relation to energy use for space heating, cooling and lighting. Furthermore, it was possible to find the optimal combination of design parameters to minimise energy demands.

A study of Poirazis et al. (2008) indicated that the energy use for space heating in the cellular office is higher than for the open-plan ones. Moreover, the open-plan offices were warmer than the cellular offices, thereby a greater demand for cooling energy. The findings of their study are similar to this paper. This paper showed that the heating energy demand was almost 3 times higher for the cellular office layout than for the open-plan office. In contrast, the cooling demand was much lower for the cellular office layout than for the open-plan office.

In our study, spatial layouts showed to be an important factor in energy performance. Overall, the flex office was the most efficient layout for the total energy demand, with around 17% of energy savings compared to the open-plan office, which had the highest energy demand. Next to the flex office, the cellular one was the second most efficient office layout. The reason for this is that the flex office has less individual rooms that have a higher heating energy demand. Although the total energy demand was not significantly different between the cellular and the combi office, the combi office required less heating energy than the cellular one.

The outcomes from this study support previous studies. Goia (2016) revealed that the range of optimal WWR is narrow: between 30% to 45%, regardless of different climates in Europe. Moreover, the impact of the WWR on energy use is less sensitive in a cold climate than in a warm climate. From his findings, it can be assumed that solar radiation would be the main impact factor related to determining glazing areas according to the orientation. Raji et al. (2016) stated that a smaller glazing area achieves a higher percentage of energy savings for heating and cooling. As the results are shown in this study, a WWR of 30% was the optimal case for energy efficiency, which is in line with the previous study. Approximately 40% and 48% of heating energy savings were simulated for the workspace with a WWR of 30% compared to that of 50% and 80% respectively, and 18% and 35% of cooling energy savings.

However, there is a different opinion regarding the WWR. Having a small glazing area would not be an optimal solution in every case. Due to a lack of daylight, workspaces with a small WWR required more energy for lighting. On the other hand, the higher heating and cooling energy demand required for a workspace with WWR of 80% was mainly due to the solar radiation in summer and due to heat losses through the windows in winter.

Based on the result, the orientation was not a significant factor in the total energy use, as Poirazis et al. (2008) revealed. The study in this paper did not distinguish between workspaces facing different orientations, making it difficult to analyse the impact of different orientations on energy loads. Nevertheless, it is assumed that north-facing workspaces in the northern hemisphere may encounter higher energy consumption for heating and lighting because of a lack of sunlight. One way to reduce the total energy demand can be to have a larger glazing area for north-facing workspaces, reducing the energy demand for lighting. Chen et al. (2018) also suggested that the optimum design for lighting and cooling is oriented to the north by avoiding direct solar radiation.

7.7.2 Impact of occupancy and lighting on energy performance

Occupancy density and lighting may cause a different energy demand in each model. In this study, the occupancy density was the same for open, combi, and flex offices, and the cellular office accommodated one person more than other typologies. Nevertheless, the heating demand of the cellular office was relatively higher than other office layouts. The internal heating production would be different according to the number of people in a workstation. For example, a workstation in the open-plan office is shared among 15 people who produce heat; therefore, the heating loads can decrease.

The reason for the energy demand gap between the cellular and open-plan office can be explained by the different requirements for lighting illuminance in office layouts. For instance, the cellular office layout includes a corridor that requires less lighting illuminance than the workspaces themselves. Therefore, the cellular office had the lowest, and the open-plan office had the highest energy demand for lighting.

7.7.3 Limitation

Simulating only the working space of one floor is a limitation of this study. For example, the energy gain from solar radiation may be different according to the floor height because of the different sun angles reaching the windows, which is also dependent on buildings in the surrounding area. In addition, support spaces, such as circulation areas, pantries, and large meeting rooms were excluded from this energy simulation. When these spaces are considered, the total end-use energy demand will increase. However, this simplified simulation approach is mostly conducted in energy simulation research to decrease the simulation running time and to simplify the models (Jung et al., 2018).

Different types of glazing can also bring a different energy demand. According to Poirazis et al. (2008), there is a different heating and cooling energy use between office spaces supplied with double glazing and triple glazing. Their study showed that, for heating and cooling, the office space with triple glazing and a WWR of 30% used 4-9 kWh/m2 more than the one with double glazing and the same WWR. Moreover, when the WWR increases the double-glazed office space uses more energy for heating and less for cooling than the triple-glazed one. The use of renewable energy, such as solar thermal system and photovoltaics, was not considered in this assessment. However, implementation of renewable energy in buildings will be an important parameter for studies of nearly-zero-energy buildings (Ahmed et al., 2018; Paoletti et al., 2017).

7.8 Conclusion

This chapter investigated the impact of design factors on the energy demand of workspaces by using an energy simulation tool. The objective was fulfilled by simulating 24 alternative workspace models. For existing office renovations, the orientation of the building cannot be changed, and the impact of the orientation on the energy demand is insignificant. Spatial layout and WWR are the important determinants of energy loads. It is possible to characterise the optimal design solutions for a specific building orientation. The energy efficiency of an office area highly depends on the office layout and the glazing area of a façade.

7.8.1 Office layout

The results demonstrated that different combinations of office design parameters influence the primary energy demand. It is worth noting how different design factors contribute to the energy demand. Layout-based results showed that the cellular and flex offices were more energy-efficient layouts compared to open-plan office models. Although the cellular office showed the lowest total energy demand, having more cellular rooms required more energy for heating. In contrast, open-plan offices had a much lower energy demand for heating, but they showed the highest total energy demand due to the high cooling demand. Therefore, it is worthwhile to investigate how cooling loads can be reduced in the open-plan office and heating loads in the cellular office.

7.8.2 Window to wall ratio and orientation

The glazing area of a façade was highly relevant for the energy demand. A larger WWR showed a greater energy demand for heating and cooling and a lower energy demand for lighting. There was a drastic increase of the energy demand for cooling between the workspaces having a WWR of 30% and 50%. The energy demand for lighting decreased around one fifth when the WWR increased from 30% to 50%. The energy demand for lighting decreased by approximately 11% when the WWR increased from 50% to 80%. Although an 80% glazing area could reduce the amount of energy used for lighting, for the total energy demand, a lower WWR is recommended for any combination of office types.

No significant difference was seen in energy demands according to different orientations. Since office buildings often have at least two opposite sides of window facades, the total energy loads may be compensated by the different indoor conditions of opposite orientations. When designing large glazed office buildings, the cooling demand should be studied well to decrease the total energy demand.

7.8.3 Recommendations

A certain combination of design parameters is recommended for the energy savings by office renovation. As a strategic tool, energy demand data may contribute to the conceptual renovation design phase. The most energy saving model in this paper is a cellular office with a WWR of 30%, followed by a flex office with a WWR of 50%

and 30%. Ideally, a WWR of 30% is recommended for combi and open-plan offices. Although having a large glazing area is not preferred for energy efficiency, a WWR of 80% may be applicable to the flex office. This typology would be more efficient than the open-plan office with any glazing area and the cellular office with a WWR of 80%. These outcomes are potentially valuable for architects, façade designers, and facility managers to design renovation plans.

To develop effective office renovation options further, renewable energy systems such as solar collectors and photovoltaic panels should be integrated into simulation models. The aim of this study was limited to energy efficiency, indifferent to the source of the energy used.

Providing offices where people are satisfied with their working environment is essential for successful office renovations in practice. Therefore, occupant satisfaction should be considered with energy-efficient models as well.

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