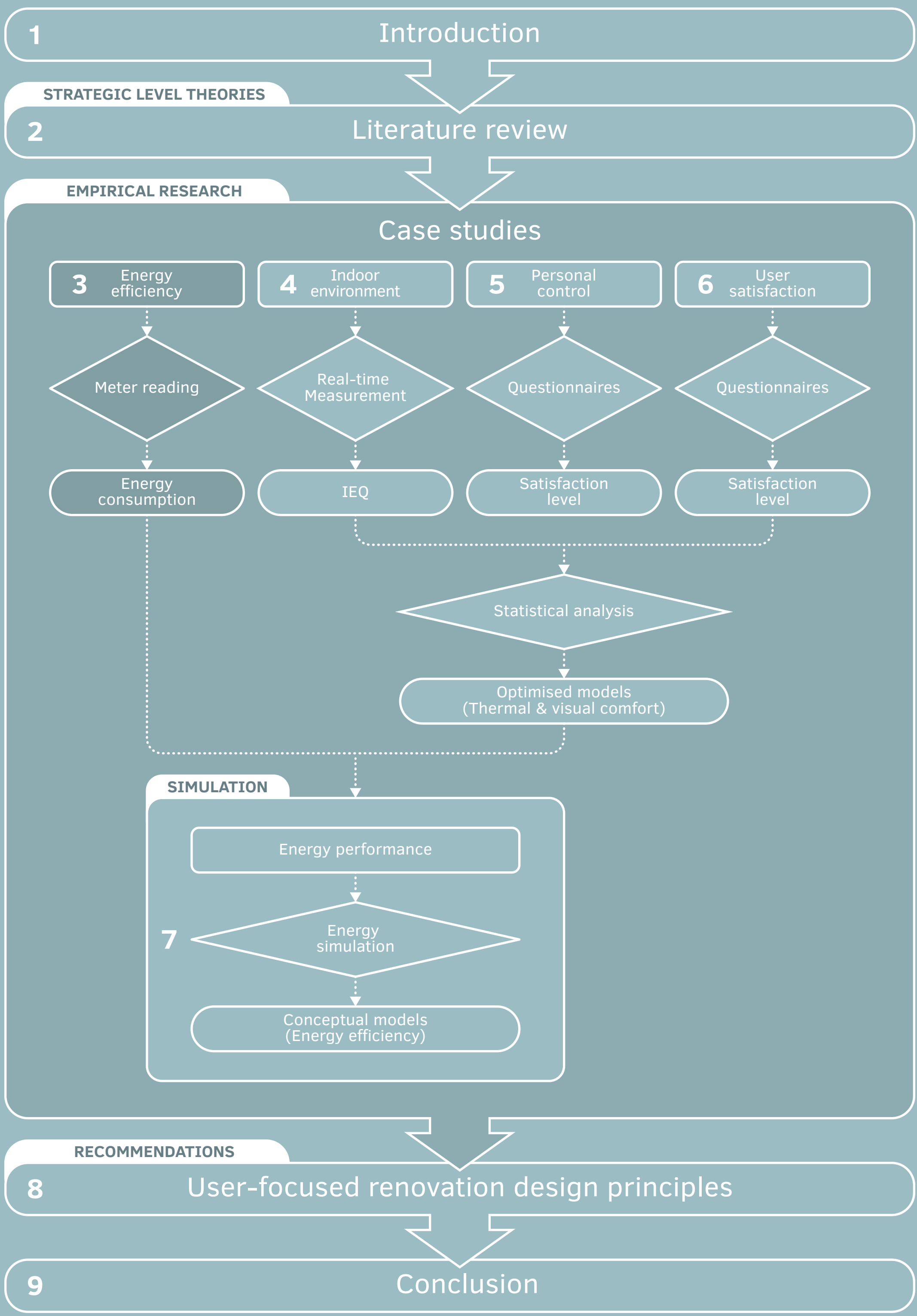
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3 Building characteristics and energy use of energy-efficient renovated offices

Chapter 2 presented the physical and psychological satisfaction parameters for user-focused evaluation. In most renovation projects, the façade is a major consideration next to the HVAC system to optimise the performance of the building. Many studies reveal that façade renovation has a large impact on the energy efficiency. The aim of this chapter is to identify the characteristics of renovated offices, such as façade types, HVAC system, and sun shading, and compare the energy performance based on user typologies in renovated and non-renovated office buildings.

Section 3.2 describes an overview of façade renovation strategies based on literature. The renovation strategies are classified into four strategies: passive add-in, replacement, climate skin, and active add-in. Section 3.3 presents the criteria to select case studies. Section 3.4 describes the characteristics of four renovated case studies and one non-renovated case located in the Netherlands. The building information was collected through interviews with architects, a review of project documents, and a field survey. Cross-analysis was used to compare the renovation plan, physical conditions. Energy consumption of each office building was compared by different energy metrics in section 3.5. Section 3.6 discusses the limitation of the renovation projects and suggestions for the future study. The finding from cross-evaluation of case studies are described in section 3.7.

3.1 Introduction

Energy-efficient building renovation has received wide attention, particularly during the last decade. The EU has ambitious goals for energy reduction. According to the European commission and Energy Performance of Buildings Directive (EPBD, 2010; EuropeanCommission, 2016), compared to 2005, by 2050 the primary energy demand should be reduced by 32-41%. Many studies have stated that the building renovation is an important key to achieve this goal (Bournas et al., 2016; BPIE, 2013; Kamenders et al., 2014; Marszal et al., 2011; Risholt et al., 2013).

The building façade is one of the major considerations in the building renovation. There are two reasons why facade technology is important for the renovation. Firstly, the façade can significantly reduce the amount of energy use. According to Feng and Hewage (2014), 26% of the total building energy is lost through the façade in a cold climate zone. Susorova et al. (2013) stated that unwanted heat gain and loss occur through facades (This implies that improving the performance of the building envelop is important to save dissipated energy. Second, the façade contributes to create indoor environment quality, and influences energy consumption and thermal comfort (Echenagucia et al., 2015; Huang et al., 2013). Recent studies elaborated the paradigm shift of facade technologies from a single function to a multi-functional façade that responds and adapts to outdoor climate conditions (Ahmed et al., 2015). Capeluto and Ochoa (2017) stated that:

'an intelligent building envelope will be understood as the outer layer of a building, designed through a specific process for adaptability to the challenges posed by interior and exterior conditions using minimum energy'.

This paradigm shift is mainly caused by the increasing awareness of the indoor comfort and the need of reducing energy consumption (Knaack et al., 2014). Comparing different scales of renovation strategies is required to establish a general overview that contributes to the pre-design phase of the renovation process. Cross-analysis is used to compare the building characteristics of different offices, such as façade structure, HVAC system, window-to-wall ratio (WWR), façade configuration, and so on. Another issue in the cross-analysis is the energy units. Conventional annual energy consumption is given by kWh/m2/year. However, using this measure makes it difficult to compare energy use of offices due to the different occupied hours and the number of occupants. Therefore, the different metrics such as kWh/occupied hour, kWh/person, and Wh/m2h are proposed to normalise the energy consumption unit by considering various sizes of buildings, occupant time, and system running hours.

3.2 Literature review

3.2.1 Façade renovation strategies for optimal energy efficiency

The building envelope plays a key role in building renovation, because it determines the comfort level, day-lighting, natural ventilation and the amount of energy used for heating and cooling. Approximately 50-80% of the energy used is consumed for heating and cooling in offices (Birchall et al., 2014; Pérez-Lombard et al., 2008). Advanced façade renovation can save heating and cooling energy use by up to 50-60 % (IEA, 2013). System-based façades, such as where mechanical services are integrated into the building envelope, the so-called integrated façade (Knaack et al., 2014), could provide advantages to reduce the energy demand (Favoino et al., 2014). The key role of the building envelope for energy efficiency is not simply to focus on increasing the thermal insulation, which was done until recent times (Ruparathna et al., 2016), but also to pay attention to the system scale, such as façade systems integrating a ventilation system (Ciampi et al., 2003; Coydon et al., 2016; Ibañez-Puy et al., 2017; Stec & Paassen, 2005), adaptive façade (Perino & Serra, 2015; Ruparathna et al., 2016), solar radiation, solar control systems etc. (Silva et al., 2016; Valladares-Rendón et al., 2017).

Owing to the countless façade technologies and availabilities, it is necessary to identify the general concept of renovation strategies and their effect on the indoor climate and energy efficiency. Different strategies are defined according to the extent of façade intervention (see TABLE 3.1), which has influence on the appearance of the building. Agliardi et al. (2018) classified the possible façade addition for deep energy renovation. However, this classification does not contain a simple façade replacement. Façade renovation strategies of Konstantinou (2014) classified various types of principles for façade intervention, covering most basic strategies. Ebbert (2012) categorised three different strategies, focusing on climate design and integration of façade and building service. Rey (2004) included architectural attitude in a renovation project such as the appearance of a building. In this study, the renovation strategies are classified by integrating the change of building appearance and basic principles that cover most basic renovation strategies of façade. The strategies are ordered in a way of renovation from passive to active.

TABLE 3.1 Identification of facade renovation strategies based on literature

Reference	Strategies	Description
Agliardi et al. (2018)	Completing	The Addition is 'filling' and 'completing' the existing empty spaces, urban voids and left out sections that make the volume 'incomplete'.
	Adding	The Addition consists in aside or front apposition of extra new elements, like extensions of the existing one.
	Topping	The topping-Addition consists of an extension of the existing building by an increase in height through the construction of extra floors, new volumes or new prefabricated elements on top of the existing one.
	Translating	The Addition here happens with no uniform character, with the aim of transforming and re-defining the entire envelope and layout of the existing building.
	Extending	The Addition is a side extension on the blind wall side as continuation of the existing building.
Konstantinou (2014)	Replace	Old façade elements are removed and replaced with new ones
	Add-in	Upgrade from inside
	Wrap-it	Wrapping the building in a second layer
	Add-on	New structure is added on the existing building
	Cover-it	Cover parts or entire internal and external courtyards and atria
Ebbert (2012)	Necessary restoration solution	Existing windows and climate-units are replaced and extra insulation added
	Optimising energy saving	Installation of a climate skin
	Integral planning of façade layer	New façade takes advantage of the existing service
Rey (2004)	Stabilization strategy (STA)	A set of incremental interventions that do not fundamentally modify either the substance or the appearance of the building
	Substitution strategy (SUB)	A complete change of certain elements and simultaneously a transformation of the substance and the appearance of the building
	Double-skin facade strategy (DSF)	Partially stabilising the existing façade and adding a new glass skin, and maintaining a large part of the original building.

FIG. 3.1 provides an overview of renovation strategies for building envelopes, classified, interpreted and informed based on TABLE 3.1. These strategies aim to improve energy and building performance.

The main criteria for the selection of four strategies are based on the following conditions:

- Presenting different degrees of renovation strategies
- Establishing a general overview of façade renovation
- Considering architectural and technical issues of façade renovation

The 'Add-in' strategy is a passive way of renovation by supplementing thermal capacity to the wall and windows without substantial change of the building appearance. A new layer is added to the inside wall. Adding or increasing extra insulation layers is mainly included in this strategy. ‘Replace’ is the way to improve the façade quality and energy performance of a building by replacing existing façade elements with thermally efficient glazing, or replacing the whole façade. ‘Climate skin’ is a means to remove the complete existing façade, and then installing a new skin. The new façade concept is based on the building’s climate design, and the appearance of the building is partially or totally transformed. The last scheme is ‘Active add-in’ with integration of different climate functions such as ventilation, heating, cooling and controlling the level of lighting. The Climate Adaptive Skin (CAS) concept is an example of integration of building services into the façade system (Hasselaar et al., 2010).

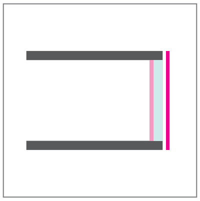
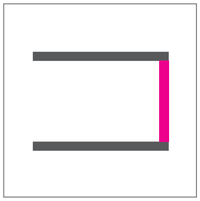
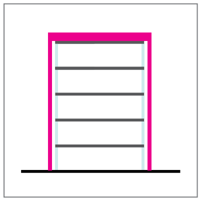
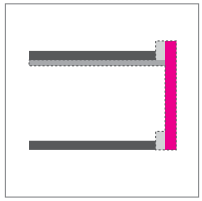
Passive add-in	Replacement	Climate skin	Active add-in
			
Adding layers to the inside wall or the outside to upgrade energy performance without change of the substance and the appearance of the building.	Replacing or removing existing façade elements, and the appearance of the building is partially or totally transformed.	Installing a new façade or adding a new layer to the existing building envelope. The new skin concept is based on climate design and the appearance of the building is partially or totally transformed.	Single skin system with integration of different façade systems to upgrade energy performance of the building.

FIG. 3.1 Classification of renovation strategies for the building envelope

3.3 Case study selection

The scope of this chapter is to study the range of renovation strategies that have been established over the last decade, and learning from case studies. Three methods are chosen to obtain information about the physical building condition: literature study, interviews, and case studies. A multiple case study is applied to

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compare representative renovation cases. In general, a single case study is suitable for in-depth research (Greene & David, 1984), whereas a multiple case study can be conducted to generalise the results through a cross-comparative analysis.

Four façade renovation strategies based on literature reviews are selected for in-depth study according to a different extent of façade renovation (see TABLE 3.1). The four strategies are: passive add-in, replace, climate skin, and active add-in. Based on these preconditions, four renovated office buildings located in the Netherlands are selected for the case studies, meeting the following criteria:

- originally built in the 1960s to 1980s
- occupied at least over one year after renovation
- highly energy-efficient labelled offices
- can provide over one-year energy-use data
- façade renovation is the main part of the renovation

TABLE 3.2 Classification of building information used in case studies

Building description	Building services	Room and interior
Year of original construction	Lighting (to optimise the use of daylight)	Office type
Year of renovation	Heating/cooling	Ceiling height
Building storeys	Cooling production plant	Occupancy density
Roof structure	Heating/cooling distribution network	Lighting
Type of glazing	Room temperature control	Type of window frames
Sun shades	Temperature set point	Main light control
Building shape	Ventilation	Sun-shading devices
Building occupancy time	Type of mechanical ventilation	Openable windows
Building size	Control system for mechanical ventilation	Location of air supply devices
	Air handling units (AHUs)	Heating/cooling system
	Type of heat recovery	Ceiling type
	Position of ventilation system	

The selected offices have to generate comparable data because each office has a different shape, size and condition. Thus, a standard checklist was designed to generalise the results and to establish research boundaries. TABLE 3.2 shows the building checklists referenced from ‘The healthy indoor environment’ (Bluyssen, 2013) to compare case studies. The checklist provides the fundamental questions to collect essential information. It has three categories: building description; building services regarding HVAC; and room and interior. Only relevant energy subjects were adapted in this study.

At the same time, interviews were conducted to collect technique-related information such as information on physical properties, adapted renovation techniques, and design approaches, between April and May 2017. Interviewees are architects who involved in the renovation projects and facility managers of the case buildings.

3.4 Building information of case studies

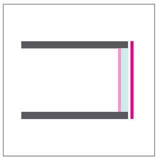
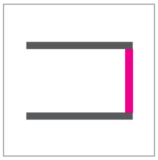
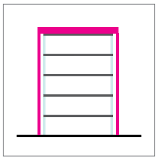
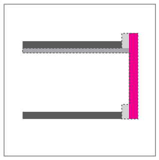
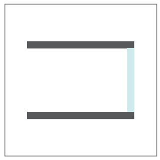
	Case A	Case B	Case C	Case D	Case E
	Passive add-in	Replacement	Climate skin	Active add-in	No renovation
Case					
Façade renovation					
WWR	£ 30%	£ 80%	£ 50%	£ 50%	£ 30%
Location	The Hague	Amersfoort	The Hague	The Hague	Delft
Built year	1973	1971	1975	1960s	1960s
Adaptation	2010 – 2011	2012	2008	2012	
Available size	Available size: 6,000 m^2/ 3989 m^2 (use space), 5 storeys	Available size: 19,200 m^2, 2 storeys	Available size: 66,000 m^2, 7 storeys	18,000 m^2, 16 storeys	18,504 m^2, 7 storeys
Energy label improvement	F to A (EPC)	G to A (EPC)	Energy label A, BREEAM Very good	BREEAM Excellent	No measurement

FIG. 3.2 The information of case studies (photos by the author)

3.4.1 Passive add-in

Case A was an outdated and abandoned office building built in the 1980s, in The Hague, the Netherlands. The office building had been vacant for two years before renovation. However, since renovation, all spaces have been rented out. The main change is the addition of a glass layer in front of the existing façade and adding new insulation layers from the inside. The existing façade is kept so that the project could been done in a short renovation period, within three months. Worthy to note is the HVAC system: The building uses an air-to-air heat exchanger installed on the roof. The heat exchanger serves cooling, heating and ventilation through the ceiling. The office spaces do not need extra radiators during winter. Employees can control the temperature in their office room individually. The system allowed to increase the floor-to-ceiling height from 2.4 m to 2.55 m by replacing the old massive ducts. This makes it possible to provide sufficient daylight for work spaces. Before, the 21.6 m deep floor plan and low ceiling height created relatively dark spaces in the middle part of the floors. By cutting off the concrete floor and creating staircases in the middle, the space provides more spaciousness and more light.

Façade renovation

The main façade is oriented to the NW and SE. The original façade had a window-to-wall ratio (WWR) of 45%. The façade consisted of prefabricated concrete panels attached to floors. It was a load-bearing façade structure without insulation. A remarkable point in this façade renovation is that two different concepts for the north and south façade are applied to the building. The building originally had no insulation layer in the wall and had single-glazed windows with wood frames. During the renovation, a new insulation layer of 100 mm thickness was added to the inside of the walls, and the single glazing was replaced with HR++ glazing, with a U-value of 1.1 and C-value of 2.5. The south façade got manual sunscreens so that users can control them individually. The south façade configuration was not changed and kept its original appearance. The north façade has a more important role for the building image since it faces the main access of the building. In this case, the new glass façade has a more architectural than functional value. Nevertheless, the glass layer allows people to open windows without being hindered by wind.

Energy efficiency

Case A achieved energy label A, coming from F, mainly due to the new insulation layer to the façade and to replacement of the HVAC system. After renovation, the building consumed 353,244 kWh in 2014 and 335,071 kWh in 2015. On average, a workspace uses 57 kWh/m^2 of electricity and 2 m^3 (19.54 kWh) of gas. The heat exchanger serves heating, cooling and ventilation in one system, so that workspaces do not require extra radiators or air condition. The warm and cool air is distributed through the ceiling connected to ducts. People can adjust their room temperature individually, but they cannot set an extreme warm or cold indoor temperature.
The office spaces use automatic sensors for the lighting. These also contribute to reducing the electric energy consumption.

3.4.2 Replacement

Case B is a successful office building renovation in the Netherlands, achieving a high energy label rating. The first renovation was conducted in 2006 and mainly focused on the building façade, which was outdated and falling apart. There were basic requirements for the beginning of the office renovation. The main aim of the renovation was to achieve energy savings, improve fire safety, replacing the old façade, achieve an equal comfort level at least, and all of this should be achieved for a limited budget.

Façade renovation

In terms of design, façade replacement was the main part of this office renovation. The existing façade with wood frames was replaced by a fully glazed façade with HR++ glass. It provides more daylight and solar-controlled sun-blinds preventing over-heating. Although the building has no natural ventilation, the building envelope was improved by adding 9 cm of roof insulation and finishing it with light-coloured roofing material. The light coloured roof results in a cooler building during summer and it reduces the use of air-conditioning.

Energy efficiency

According to the energy consumption data measured by meter reading, after renovation the office saved 31% of electricity compared to before renovation, and a reduction of 56.4% was achieved for the use of gas. On average, per square meter, workspaces use 88.25 kWh of electricity and 3.26 m^3 (31.85 kWh) of gas. The electricity energy is fully supplied by wind energy. The office uses pre-occupancy cooling during night and the central air handling units (AHU) provide heating and cooling through a water cooled chiller + cooling tower. In addition to this system, the building heats the occupied spaces by a solar collector.

3.4.3 Climate skin

Case C was one of the examples of brutalist buildings in the Netherlands, with a huge and fortress-like concrete façade. The image of the building was closed and unfriendly. Moreover, office users also struggled with the working environment. Therefore, the purpose of renovation was focused on comfort in the working environment, energy efficiency and creating a friendlier and open image to citizens. Wrapping the concrete structure with a new glass façade was one of the main measures applied to this office building. The original structure could be preserved by wrapping the original façade, reducing renovation costs. As a result, the new transparent façade created a lively and modern building image. The building originally had two internal courtyards. However, one of them was converted to a winter garden by covering it with a glass roof. The garden provides a playful space to people.

Façade renovation

Although the main contribution to energy saving in this renovation was by the use of an aquifer thermal energy system (ATES), a double-skin façade (glazing: heat resistant, U-value 1.2 W/m^2K) also created substantial energy savings with the integration of a thermal buffer and climate ceiling. A single glass was put in front the second glass skin, and a thermal layer was created in front of the existing façade. The original façade structure supports the second layer so that the original structure is completely maintained. The double-skin façade helps to prevent cold draughts by a buffer zone between the original façade and concrete balcony element. The buffer zone also contributes to improved acoustics. 80% of the total window area is openable and the WWR is 57%, which allows more natural daylight. External sun-shading blinds were installed for all facades, and they are automatically let down but can be individually controlled.

Energy efficiency

Annual energy consumption data were available from after renovation. For comparing energy consumption, the average number of the last four years, from 2013 to 2016, was used. On average, the building now uses 67.58 kWh of electricity and 3.9 m^3 (38.10 kWh) of gas per square meter. In total, over 2200 people work in the office, and the building serves around 2000 desks to work at. The building occupancy rate is around 65 to 70% which means that around 1430 to 1540 of the total number of employees appear during working days. After renovation the energy performance coefficient (EPC) of the building was 0.89 which is considerably lower than the required 1.40.

3.4.4 Active add-in

Case D, originally built in the 1960s, was renovated and extended in 2012. It is located in the new central business district in The Hague. It has 18,000 m^2 of office space on 16 storeys, providing around 1230 working desks. The existing structure had many columns. After calculation, several columns could be removed and the building could be wrapped with a new glass façade. As a result, the office with less columns could provide more open view and natural daylight. The ceiling height was increased to 2.7 m by replacing the HVAC system in the ceiling.

Façade renovation

The building has a shallow-depth floor with a length of 66 m and a width of 15 m. The skeleton façade structure had small columns every 1.5 m. By removing the façade columns every 3.0 m, one third of void area in the original façade could be extended to two thirds of void. Now the columns are situated every 3 m. The WWR of the new façade is 51%, with an R-value of 3.5 m^2K/W. The south-east façade has a double sun shading system, interior and exterior, to prevent over-heating of workspace. The façade is one of the façade cases with the integration of ventilation systems behind of the structure.

Energy efficiency

The office was rated Excellent by BREEAM-NL. Energy consumption data was collected by meter measuring in the whole building for the period of January to March 2017. The building uses 304,458 kWh during power peak and 161,028 kWh during off-peak. Approximately 155,162 kWh of electricity is used per month. The annual energy consumption is around 103.44 kWh/m^2 for the Gross Floor Area (GFA).

3.4.5 Non-renovated office

Case E represents the most common office type built between 1960s and 1970s in Delft, the Netherlands. The building has under 30% WWR with single glazing. This building in general is poorly insulated. Each office room has a radiator that is individually controlled and does not have a cooling system. During summer, the cellular office can be cooled down by opening windows, and internal blind can be controlled by occupants.

3.5 Energy consumption compared by different units

The annual total energy consumption represents the energy delivered from the outside, and it was collected by meter-reading from each office building. The energy use includes annual electricity and gas use for heating, cooling, ventilation and equipment. TABLE 3.3 shows the energy consumption of case studies with various metrics.

The total energy consumption from meter-reading divided by the floor area on a yearly base is equal kWh/m2/year. kWh/year divided by running hours results in kWh/hour. However, the international unit kWh/m2/year can be differently interpreted regarding to the occupancy rate. The metric, kWh/person is calculated by annual energy consumption per year divided by occupancy number in daily base per year. The metric, Wh/m2h is the calculated annual energy consumption per square meter divided by the total occupied hours in a year (Dooley, 2011).

TABLE 3.3 Normalising energy consumption with various metrics to compare offices in different conditions

Energy consumption						
	kWh/m²/year	System running hours/ year	kWh/hour	Occupancy number/day	kWh/person/ day	Wh/ m²h
Case A	79.47	2544	135.28	94	14.65	0.39
Case B	125.25	2915	602.81	468	15.02	0.12
Case C	111.20	3180	2307.92	1485	19.77	0.04
Case D	108.38	4240	460.12	829	9.41	0.06
Case E	361.00	4770	1400.38	1100	24.29	0.15

When we compare the conventional energy consumption of each office, Case B (replace) uses the largest amount of energy, and Case A (passive add-in) the least. However, the four different offices have a different number of employees, and different system running hours. Therefore, other metrics are used to compare them from diverse perspectives. As we consider how much energy each person consumes, a person in Case D (active add-in) uses the least amount of energy, 9.41 kWh/day. In contrast, a person in Case C (climate skin) consumes 19.77 kWh/day of energy. As occupied hours considered, Case C and Case D consume around 1/6 to 1/8 times less energy than the most energy used office (Case A). Inconsistent results were shown due to the different number of occupants.

3.6 Discussion

3.6.1 Learning from case studies

This study shows three major barriers that hinder achieving better energy performance. The major barriers found in the cases are: implementation defects, structural limitations and an over-designed plan. First of all, case A has structural limitations. Windows were changed from single glazing to HR++ double glazing, and new insulation was added from the inside of the building. The limitation of this case is the load-bearing façade structure. Interestingly, a new glass layer was added to the north façade only for the aesthetic aspect, instead of energy efficiency or functionality. However, after renovation, the new glass layer contributes not only to refreshing the building image but also to blocking off harsh winds, so that people can open windows for natural ventilation. Although there was a structural limitation, case A shows the highest energy saving after renovation.

Case B was renovated with an over-focused design plan. This building adapted the replace strategy. The HVAC system and the whole façade were replaced to an efficient HVAC system and air-tight new windows, which can significantly reduce the energy demand. Nevertheless, the office encounters over-heating problems due to the increased window area. As a result, sun-blinds were installed inefficiently on every elevation of façade. By increasing the glazed area, occupants have a better view outside and this also expresses a modernised building image (according to current standards). On the other hand, glazed buildings are likely to overheat during summer and become cold in winter. In other words, a large amount of window area is an conflicting point between energy efficiency and architectural demand.

Case C has an implementation defect. The double-skin façade concept is helpful to reduce the primary energy demand by pre-heating fresh air during heating seasons and by extracting air through the cavity during cooling seasons. Basically, the outer layer of the double-skin façade functions to pre-heat fresh air from the outside and ventilate exhaust air to the top. The cavity between the outer and inner layer can be opened and closed. However, case C does not have openable panels for the cavity. The building shows a relatively high energy consumption compared to the other case studies. The new façade does not contribute to energy reduction because the strategy was not correctly implemented to the building.

Case D shows a similar design approach which is ‘replace’, but this renovation has better results than case B, with the second highest energy saving. Furthermore, the WWR is also quite high, like that of case B. We can assume two reasons why case D shows better results. First, the ventilation-integrated façade contributes to energy savings. Second, although the building has openable windows, people are not allowed to open windows. As a result, an unpredictable indoor condition is avoided, and the indoor climate is only controlled by a central-heating and cooling system.

3.6.2 Limitations

The limitation of a case study in this chapter is the difficulty of identifying causality. Ideally, comparing energy and building performances before and after renovation would have been a stronger research design to investigate the impact of renovation

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on the performances. However, due to the limited timeframe, it was difficult to use a before-and-after design.

Energy performance is influenced by types of operation pattern, user control, indoor comfort, HVAC system, energy supply, night ventilation and so on. Indoor comfort is, particularly, an important factor in energy performance since it affects the system running hours and the climate control to provide comfortable indoor environment to occupants. This chapter mainly explores the characteristics of renovated office buildings and whether the renovated office buildings are functioning well in terms of energy efficiency. Although the office buildings are improved to achieve better energy labels, the actual use and condition of the offices do not qualify to the planned condition. Therefore, it is important to investigate the building characteristics and design factors and their impacts on the work environment. In addition, the occupant is a major factor in energy consumption. For the future research, it will be important to identify general occupant types before we understand occupant behaviour and energy use patterns.

3.7 Conclusion

This chapter analysed four renovated office buildings to understand the building characteristics of renovated offices and presented a comparative evaluation of the energy consumption by means of various metrics. The results were mainly evaluated on the basis of real-time observation during field studies. Appendix B compares the characteristics of renovated office buildings, such as façade structure and configuration, WWR, sun-shadings, glazing types, HVAC system, heat recovery, openable windows, system running hours, and temperature set-point. Overall, the glazing area of the façade increased, together with an improved insulation capacity of the façade after renovation. External or internal blinds were installed to prevent glare and over-heating. Renovated offices often have a heat recovery system with improved HVAC systems. Due to safety reasons, occupants are not allowed to open windows in high-rise offices.

The main findings from this study include the following. (1) The strategy of façade renovations is mainly decided by the existing condition of the façade structure and budget. (2) Various metrics should be applied to compare the energy use of different buildings. kWh/person and Wh/m^2h can be appropriate to use, to compare energy consumption of buildings. (3) During the design stage, architects need to fully consider the quality of the indoor climate to prevent inefficient energy use. For example, if a building has a large glazing area, this causes over-heating or heat loss problems, which leads to more energy use for indoor comfort, and the building eventually needs extra layers to reduce the heat loss or over-heating. Thus, the design phase should give better attention to the balance between energy use and indoor climate. (4) During the construction phase, engineers need a full understanding of the design strategy. The principle of climate design should be implemented to the building correctly without missing any component or being compromised by the budget. (5) During the operation phase, occupants are required to understand the right way of operating the climate system for the indoor comfort. The right way of climate control can contribute to effective energy use.

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