Rethinking energy conservation via an evaluation of the heating system: A Case Study of Zilverling, University of Twente

by

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"Happiness is not a station you arrive at, but a manner of travelling"

Margaret Lee Runbeck

UNIVERSITY OF TWENTE

Abstract

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The purpose of this research is to study the heating system in Zilverling building and find some possibilities to conserve the energy. The first step of this research investigates the static model based on degree day method. Thereafter, the dynamic model using thermal resistance network is developed. After obtaining both the static and dynamic models, the result is compared to find some strategies for energy improvement.

The simulation from static and dynamic model shows that the building is well maintained. However further investigation give some insights in the possibility to safe energy by applying better control algorithms for the heating and cooling system.

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Contents

List of Figures

Chapter 1

Introduction

Energy is a hot topic today. As fossil fuel becomes increasingly scarce due to the rapid increase in global energy demand, the question of sustainability becomes a pressing issue. In recent years, there has been growing research interest in finding alternative energy sources and optimizing attempts in energy conservation.

One of the research highlights in the energy field is the energy systems in built environment. This is logical since according to some studies, buildings take up 37%-40% of global energy consumption [see e.g.,[1, 16]]. Thus, a comprehensive research on improving energy consumption in buildings is expected to yield significant improvements in global energy conservation.

1.1 European Union goal

The EU actively champions for energy conservation via rules and directions set by its commission. Known as the "20-20-20" targets, EU sets three key objectives for 2020 energy sector plan [13]:

- a 20% reduction in EU greenhouse gas emissions from 1990 levels,
- raising the share of EU energy consumption produced from renewable resources to 20%,
- and 20% improvement in the EU's energy efficiency.

Another law is directive 2010/31/EU (EPBD recast), article 9 requires that [10]," *Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings . Member States shall* *furthermore draw up national plans for increasing the number of nearly zero-energy buildings and following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings".*

1.2 Netherlands goal

As a committed member of EU and an environmentally conscious nation, the Netherlands government launched a program called *Clean and Efficient: New Energy for Climate Policy*. This program aims to develop Netherlands into a country with one of the most efficient and cleanest energy systems in Europe by 2020. The targets are [see e.g.,[9, 18]]:

- to cut GHG emissions by 30% from 1990 to 2020,
- to double the rate of yearly energy efficiency improvement to 2% in the coming years,
- and to reach a 20% share of renewable energy in total primary energy supply (TPES) by 2020.

1.3 University goal

As a premier academic and research institute, the University of Twente not only aims to abide by the national targets, it also seeks to further energy conservation efforts. Since the current system is able to meet the target of 2% energy efficiency improvement per year [25], the university is able to channel its efforts into energy conservation and using more renewable energy sources. The PV installation in the Horst building in 2012 is testimony of the university's commitment. This initiative is then extended to an installation of a PV test bench in 2014 for Citadel Building.

Another significant attempt is the construction of the central monitoring system for university energy usage last year. This system tracks the amount of energy used in the whole building on hourly basis, covering electricity, thermal, and water usage. While currently only utilized in the Spiegel and Zilverling building, there are plans to implement such a system in other buildings.

1.4 The goal of this thesis

This goal of this research is to study HVAC system of a building in the university, with a focus on the heating system. The goal is extended to find a strategy to improve the energy performance of the building. In this project the Zilverling is chosen as study case.

1.5 Scope of work and thesis organization

This thesis focuses extensively on the heating system. Other systems will be considered in relation to the heating system as a focal point. In this research, the investigation covers only the main part of the Zilverling building, (exclude SmartXp lab, Educafe and EEMCS office faculty area on the first floor).

This report is presented in six chapters. Chapter 1 is the introduction which explains the background and objectives of this research. Chapter 2 presents the background theory related to this project, namely the theories and prior research on thermodynamics in a building and HVAC systems. Chapter 3 presents the case study. Chapter 4 is about the Degree Days method simulation. Chapter 5 is about the dynamic model development. Some recommendation based on the result are given in Chapter 6. Finally, conclusions are drawn and some further research options are given in Chapter 7.

Chapter 2

Background Theory

This chapter presents the background and related theory to HVAC system in buildings. The first part of the chapter presents the background and general theory related to the HVAC systems in a building such as its thermal condition, thermal comfort, weather data and HVAC system, which includes heat transfer mechanisms. The second part of the chapter presents the procedure for calculating heating and cooling loads in the building. The last part of this chapter explains the degree day method as static model and dynamic modeling using thermal networks.

2.1 Building thermal conditioning and thermal comfort

Thermal conditioning of any building is vital to the functioning of a healthy human metabolism. Therefore, there is a need to monitor, maintain and ensure its standards periodically.

In [3], there are at least 3 purposes of thermal properties identification of the heat dynamics in a building: indoor climate control, accurate description of energy performance of the building, and forecasting energy consumption. To fulfill these purposes, the identification should be performed based on frequent readings of heat consumption, indoor and ambient air temperature, including other climate variables.

Comfort is defined in [2] as *condition of mind which expresses satisfaction with thermal environment*. It describes a persons psychological state of mind that is usually referred to terms of whether someone is feeling too hot or too cold.

In describing the thermal comfort, we can take six factors into account. These factors are air temperature, radiant temperature, air velocity, humidity, clothing insulation and metabolic heat [15]. The first four are environment-related factors, and the last two are personal-related factor. From the aspect listed, the most significant factor is air temperature [30].

2.2 Weather and Climate

As explained in the previous section, weather and climate conditions have major influence in defining building conditioning system. Some of major influences is listed as follow:

- site information (latitude and longitude)
- temperature data, dry bulb temperature
- humidity and moisture data (wet bulb temperature)
- solar radiation data
- cloud coverage, and
- wind data, speed and direction that influence ventilation and infiltration.

It is imperative to use the most accurate climate and weather data to determine the most optimal natural energy used in the building system, so that the active energy supply can be reduced. In defining the system specification, both seasonal and diurnal weather variation have the same importance.

2.3 Heating, Ventilation, and Air Conditioning (HVAC)

In the building environment, the HVAC system is designed to provide complete health environment and thermal comfort to the occupants by heating, humidifying, dehumidifying, cleaning and deodorizing [see e.g., [4, 22]]. The main function of the system is to provide outdoor fresh air through ventilation, remove heat and moist gain during summer and humid condition, and provide heat during cold season. To fulfill the function this system must meet criteria for different weather conditions in all seasons over the year. Two importance outputs of this system, in controlling the indoor thermal condition, are:

- heating load, the rate which energy need to be transfer to reach the desired room thermal condition, and,
- cooling load is the rate of energy needed to remove the heat from space to reach the desired air condition.

2.3.1 Heat Transfer in HVAC application

There are three basic mechanisms of heat transfer involved in HVAC system. The explanation of these mechanisms in this section is taken mainly from [22]. In inspecting heat transfer application in HVAC system, most can be treated as one-dimensional and in steady state or dynamic condition. One dimensional means that the temperature gradient are in only one direction, steady state means the system states such as temperatures and heat flow vary little or not at all in time. Dynamic means a significant or rapid variation of the system states in time. [22].

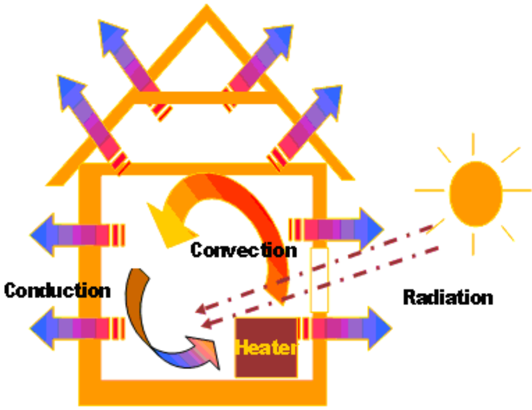

FIGURE 2.1: Mechanisms of heat transfer in building [24]

Conduction refers to the flow of heat that occurs inside structures or materials in the building. For conduction,the thermal conductivity(k) is material property, which relates heat flux through the material with the temperature gradient within the material.

$$\dot{Q}" = -k\frac{\mathrm{d}T}{\mathrm{d}x} \tag{2.1}$$

Where $\dot{Q}"$ is the heat flux per unit area, k is thermal conductivity, T is temperature, and x is the coordinate in the direction of heat flow. The total heat transfer rate $\dot{Q}$ is given by multiplying the heat flux by the area (A) of the wall normal to the heat flow.

$$\dot{Q} = -kA\frac{\mathrm{d}T}{\mathrm{d}x} \tag{2.2}$$

For the purpose of modeling and analysis, thermal resistance constant, R_{cond} , is introduced. This constant is defined as the ratio of the temperature difference to the heat flow, which allows the heat flow through the conduction plate. In equation its calculated as

$$R_{\text{cond}} = \frac{T_0 - T_L}{\dot{Q}} \tag{2.3}$$

Where $T_0 - T_L$, (ΔT), defines different temperature between each plate surface.

In HVAC application conduction mechanism occurs inside the building envelope and the concrete structures in the building, such as each layer of wall, roof, floor, window.

Convection is heat transfer, which occurs between the surface with a fluid in contact. Based on its driven force, convection is either natural and forced convection. Forced convection occurs when the fluid flow is created externally such as by pump, fan, or wind. Natural convection occurs when the fluid flow is driven by different temperature in the fluid, as in the case of downward flow of air passed cold surface.

Based on flow regimes, fluid flow can be either laminar or turbulent. For laminar flow, a fluid particle flows in relatively straight lines with no mixes between slower and faster layers. In turbulent flow the fluid mixed across the flow stream, and the thermal energy moves rapidly from higher to lower temperature region.

Based on the boundary, the convection is classified either as external or internal transfer. It is known as external when the fluid flows over a surface, heated or cooled the fluid inside the boundary layer of the surface. The internal flow occurs in situations the fluid is confined, such as flow of chilled water through a pipe in a warm space.

The basics convection mechanism equation is often termed as Newtons law of cooling

$$\dot{Q} = -h_c A(T_s - T_f) \tag{2.4}$$

Where h_c is the convection coefficient, T_s is the surface temperature and T_f is the fluid temperature. For the same purpose as conduction, convection heat transfer can be represented by thermal resistance R_{conv} ,

$$\dot{Q} = \frac{T_s - T_f}{R_{\text{conv}}} \tag{2.5}$$

where the thermal resistance R_{conv} is define as

$$R_{\text{conv}} = \frac{1}{h_c A} \tag{2.6}$$

Radiation is the heat transfer between surfaces through electromagnetic wave energy. Thermal radiation wave created when the convection inside materials reached a surface. If the surface is in vacuum, these emitted wave travel until reached another surface, if the surface is exposed to a medium, then some radiation may be absorbed by the medium.

During the transfer, thermal radiation is absorbed or reflected when it strikes molecules. As example solar radiation passes through space basically without attenuation, but a fraction of radiation is absorbed by air and other molecules as it passes through the atmosphere. In the absence of clouds 70% of solar radiation reaches the earth surface. The amount of absorption depend on the distance between surfaces. The intensity of the thermal radiation wave is related to temperature, therefore the amount of energy emitted is greater for higher temperature surface.

Related to absorption and reflection, the terms black surface, is introduced as an ideal surface that emits maximum thermal radiation. Total energy per unit area emitted by an ideal black surface over all wavelengths and angles, called total emmissive power $\dot{E}_b$.

$$\dot{E}_b = \sigma {T_s}^4 \tag{2.7}$$

Where σ is the Stefan-Boltzman constant, and T_s is the absolute temperature of the surface. On the other hand, called a gray surface as surface for which the emissivity independent of wavelength and the emission is diffuse. The radiation emitted from gray surface can be described in terms of emissivity and emissive power of an ideal surface, which shows in following equation,

$$\dot{E}_s = \varepsilon \dot{E}_b = \varepsilon \sigma {T_s}^4 \tag{2.8}$$

The fraction of irradiation that absorbed by gray surfaces is called absorptivity α. The amount of energy absorbed is

$$\dot{E}_{\text{absorbed}} = \alpha \dot{G} \tag{2.9}$$

With $\dot{G}$ as the total irradiation per unit area on a surface.

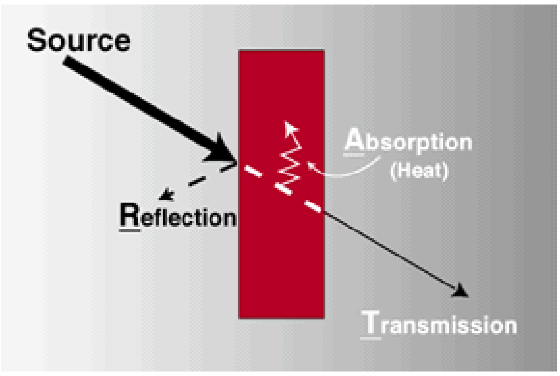

FIGURE 2.2: Absorption, transmission, reflection [6]

When radiation reaches the surface, a part of energy is absorbed. Then, the other part is either reflected back to the surrounding or transmitted to the surface. The relation between these three mechanism is

$$\alpha + \rho + \tau = 1 \tag{2.10}$$

with ρ is reflectivity, a fraction reflected irradiation, and τ is transmissivity, which define the fraction of irradiation transmitted.

Based on its wavelength, radiation is divided to short and long wave radiation. In HVAC system, the short wave radiation associate with visible light from solar radiation with high energy, while the long wave radiation is the infrared emitted by each surfaces which has low energy.

2.4 Components of building heat loss and gain

All parts of the building are involved in the heat transfer in the building. The mechanisms are considered either as heat loss or gain based on its influence to the temperature inside the building.

2.4.1 Heat flow through opaque exterior surface

Opaque surface is the surface that does not let light pass through it. In a building envelope, opaque surfaces is included roof, walls, and floors. The heat transfer within these solids is conduction.

The radiation influences the opaque surface indirectly. This means that it arrives on the surface, then absorbed and raises the temperature of the material such as wall and roof. The risen temperature on the wall means the absorbed heat. This heat is transferred trough the zone eventually when the zone temperature is lower than the wall.

Calculating the heat transfer through opaque surface in building combine the effect of convection and radiation mechanism on it. The convection mechanism transfer heat to outside surface of the wall, has the same form as presented in equation 2.4. In terms of surface and ambient temperature this equation is expressed as,

$$\dot{Q}_c = h_c A (T_A - T_{s,o}) \tag{2.11}$$

$\dot{Q}_c$ total heat transfer arrived at outside wall of opaque surface through convection. T_A is the ambient temperature, $T_{s,o}$ is the outside surface temperature. For the radiation, the mechanism is expressed as,

$$\dot{Q}_r = h_r A (T_r - T_{s,o}) \tag{2.12}$$

with $\dot{Q}_r$ is total heat transfer arrived at outside wall of opaque surface through radiation, h_r is the radiation coefficient and $T_{s,o}$ is the outside surface temperature. Combine both mechanism, the total heat transfer to outside surface expressed as,

$$\dot{Q} = (h_r + h_c) A (T_A - T_{s,o}) - h_r A (T_A - T_r) \tag{2.13}$$

2.4.2 Solar Radiation and Heat flow through glazing

Solar radiation is major energy contributor to cooling loads during summer. This occurs by direct heating window, and indirect heating (absorbed heat) on the building outer surface.

The energy from solar radiation partially reaches the earth surface by transmission, some portion of it reflected back by the upper atmosphere to the space, some part of it absorbed by the air, clouds, carbon dioxide, and other compounds, some part of it scattered by the air and other particle, which is reduced the total solar flux reach the earth surface significantly.

There are several mechanism influence of the solar radiation that reach the building surface. Called beam radiation, the energy which is transmitted directly through the atmosphere and striking the building surface. A fraction of beam radiation is scattered in the atmosphere which is called diffuse component, this component then irradiates the building surface from the sky. Another component comes from the reflection from the ground or other building surfaces.

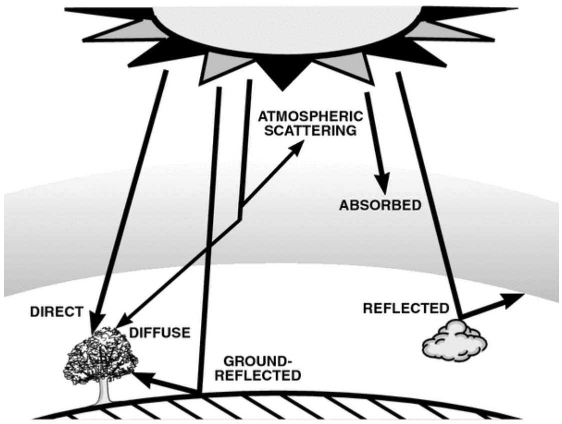

FIGURE 2.3: Solar radiation mechanism [7]

In equation the total radiation flux that is incident on the surface of a building, is the sum of beam,sky, diffuse, and ground-reflected radiation:

$$G_{T_s} = G_{b,s} + G_{d,s} + G_{gnd,s} \tag{2.14}$$

G_{T_s} is the total incident radiation per unit area, G_{b_s} is the beam radiation on the surface, $G_{d,s}$ is the diffuse radiation from the sky, and $G_{gnd,s}$ is the diffuse radiation reflected from the ground[22]. Called the g-value or solar heat gain coefficient (SHGC) which define the fraction of solar radiation incident on fenestration that is transmitted into the building.

2.4.3 Heat flows to ventilation and infiltration

Ventilation is flow of ambient air that intentionally induced into the building to provide good air quality which is controlled. On the other hand infiltration is uncontrolled airflow that enter or leave a structure, such as air leakage trough the cracks. Heat loss or gain through ventilation occurs during air exchanging process, when warm air change with the fresh outdoor air. The equation to calculate the heat loss through this mechanism is:

$$E_v = c_p \cdot \rho \cdot \dot{v}(T_i - T_A) \tag{2.15}$$

where, E_v is ventilation heat loss, c_p is specific heat capacity of air, ρ is density of air, $\dot{v}$ is air volume flow, T_i is inside air temperature, and T_A is outside air temperature.

2.4.4 Internal thermal gains

Internal thermal gains are the thermal gains from any sources inside the zone (indoor), included lights, occupants, and electricity appliances. This gains usually add to determine cooling load, while being ignored in defining heating load.

In term of its effect, internal thermal gains is divided to sensible and latent heat. Sensible heat give a direct influence to the change of temperature, in the building this kind of heat is caused by conduction and convection. On the other hand, latent heat is the heat that have correlation with the phase changing of material, in this term, the indoor air. Related to internal thermal gain, latent heat is correlated with the heat involved in water evaporation and condensation.

2.4.5 Heat flow through building elements

Discussing about heat transfer in building element cannot be separated from the discussion about heat transfer process under transient condition. Since its does not directly change the temperature as heat flow occurs through it.
Materials are capable to store thermal energy, which is called thermal mass. As the element needs time to heat up or cool down, its influence to indoor temperature change over time. In buildings, such elements included walls, roof, concrete furnitures, etc.

To investigate the behavior of thermal mass in building element, several approaches can be taken such as transfer function coefficient, radiant time series, and finite different method. The last method has an advantage in representing the problem either by physical or mathematical approach. Explanation for this method will be explained further in this chapter.

2.5 Load Calculation

Defining heating or cooling demand is basically calculating the building heat loss and gain to find the amount of energy needed to be transferred for maintaining comfortable indoor condition.

2.5.1 Heating load

Heating load is the rate which energy needs to be transferred to reach the desired room thermal condition. The determination of heating load is important in selecting the system to be installed, since the equipment is expected to meet the desired indoor condition, in all defined scenario.

In determining the heating load during design phase, the definition of extreme condition is used, which most often occur at night when building is unoccupied. Therefore, the assumption including, no solar gain trough glazing, no solar air effect on the building envelope, and no heat gains due to, occupants, light, etc.. Furthermore the building is assumed to be at steady temperature, so there is no energy released from storage. Based on this conservative assumption, the heating load define as,

$$L_H = Q_e + E_{v,s} + E_{inf,s} \tag{2.16}$$

Where L_H define heating load,Q_e is heat loss through building envelope $E_{v,s}$ defines energy loss though ventilation, and $E_{inf,s}$ define energy loss though infiltration.

2.5.2 Cooling load

Cooling load is the amount of heat energy need to be removed from a building, by the HVAC system, to maintain the expected indoor design temperature [28].

In calculating cooling loads during design phase, heat gain from appliance, solar radiation, and all heat suppliers inside the building are included. This approach is taken to describe the worst case condition (the highest expected amount of heat) need to be maintain by the system.

In defining cooling load, component that may affect are [2]:

- External: wall, roofs, windows, skylights, doors, partitions, ceilings and floors.
- Internal: lights, people, appliances, and equipment.
- Infiltration: air leakage and moisture migration.
- System: outdoor air, duct leakage and heat gain. reheat, fan and pump energy, and energy recovery.

2.5.3 Building energy balance

After defining heating and cooling load, other important concept is building energy balance which is defined the difference between building heat loss and gain. In equation the term heat balance is represented as:

$$\dot{Q}_e + \dot{Q}_{sol} + \dot{E}_g + \dot{E}_v + \dot{E}_{inf} + \dot{L}_T = \frac{\mathrm{d}E}{\mathrm{d}t} \tag{2.17}$$

Where $\dot{Q}_e$ represent envelope gains, $\dot{Q}_{sol}$ is energy from solar radiation, $\dot{E}_g$ is internal thermal gains, $\dot{E}_v$ is energy flow from ventilation, $\dot{E}_{inf}$ is energy flow from infiltration, $\dot{L}_T$ is the total building load, and $\frac{\mathrm{d}E}{\mathrm{d}t}$ is the rate of energy change in the building [22]. The positive or negative sign, represent the heat flow direction.Therefore it defines whether the particular heat is added to or subtracted from the calculation.

In order to know the actual energy usage, space load calculation of the building needs to be performed periodically. This procedure is important to evaluate, control and further improve the building system.

2.6 Modeling building thermal system, static and dynamic model

Modeling thermal condition of a building can be implemented in either steady state(static) or transient(dynamic). Both methods have different strong points, that are suitable for specific circumstances.

Under steady state conditions, heat flow is primarily a function of temperature difference and thermal resistance. Static model is suitable to describe the system for long period of time. This method can be used to calculate the total heating and cooling demand over seasons or years .

In dynamic conditions, as explained briefly in Subsection 2.4.5, heat transfer through building elements is treated as time variant function. This is due to the fact that variation of ambient temperature, internal thermal gains, and solar radiation change continuously. The dynamic model is suitable to illustrate the system behavior for short period, such as daily or weekly. This method is useful when defining the controller of thermal building system.

2.6.1 Static method: Degree day

Degree day [22] is one of the common approximation method to determine total cooling and heating energy use based on statistical weather data. This method calculates the different temperature between base and ambient, then integrate it over time. In equation, it presents as,

$$DD_{m,h} = \int_0^{N_{day}} (T_{base} - T_A)^+ \, \mathrm{d}t \tag{2.18}$$

to calculate heating degree day, while for cooling it defined as,

$$DD_{m,c} = \int_0^{N_{day}} (T_A - T_{base})^+ \, \mathrm{d}t \tag{2.19}$$

$$(x)^+ = \begin{cases} x & \text{for } x > 0 \\ 0 & \text{for } x \leq 0 \end{cases}$$

T_{base} is base temperature, defined as the outdoor temperature at which the active heating (or cooling) systems do not need to run in order to maintain comfort conditions. Related to heat balance, this temperature can be obtained from

$$T_{base} = T_Z - \frac{(\dot{Q}_{sol} + \dot{Q}_g)}{UA_o} \tag{2.20}$$

with T_Z is zone temperature, $\dot{Q}_{sol}$ is solar radiation $\dot{Q}_g$, is thermal gains U is heat loss coefficient, and A_o is surface area.

Since precise long term weather data is hard to be obtained, some studies try to simplify the calculation. Given monthly average temperature as the only input, the calculation correlate monthly degree days with monthly average temperature and statistical measure of weather variability[see e.g.,[11, 27]]. The correlation is given in following equation:

$$DDm = \sigma_m N_{day,m}^{3/2} \left(\frac{H}{2} + \frac{ln^{\frac{\exp^{-1.698H} + \exp^{1.698H}}{2}}}{3.396} + 0.2041 \right) \tag{2.21}$$

with $N_{day,m}$ is the number of the day in the month σ_m is standard deviation of the daily average temperature.

Standard deviation of the daily average temperature is given by

$$\sigma_m = 1.451 - 0.0290\bar{T}_{A,m} + 0.0369\sigma_{yr} \tag{2.22}$$

with σ_{yr} is the standard deviation of the monthly average temperature, given by

$$\sigma_y = \sqrt{\frac{\Sigma(\bar{T}_{A,m} - \bar{T}_{A,y})^2}{12}} \tag{2.23}$$

The term H is the temperature difference between base temperature, and the monthly average temperature divided by the daily average standard deviation and the number of the days in the month, which is calculated as,

$$H = \frac{(T_{base} - \bar{T}_{A,m})}{\sigma_m \sqrt{N_{day,m}}} \tag{2.24}$$

In building application, there are two main uses of degree days method. Those are:

- to estimate energy consumption and carbon dioxide emissions due to space heating and cooling for new build and major refurbishment
- for on going energy monitoring and analysis of existing buildings based on historical data [8].

The advantage of degree days technique lies in the relative ease and speed of use, since the information input required is available from the building design criteria. Contradict with full thermal simulation models degree-day calculations can be carried out manually or within computer spreadsheets.

However, it must be stressed that, degree-day techniques can only provide approximate results since there are a number of simplifying assumptions that need to be made, particularly relate to the use of average conditions (internal temperatures, casual gains, air infiltration rates, etcetera), and that these can be used in conjunction with each other to provide a good approximation of building response.[8].

2.6.2 Degree Days method for Heating and Cooling Load Estimation

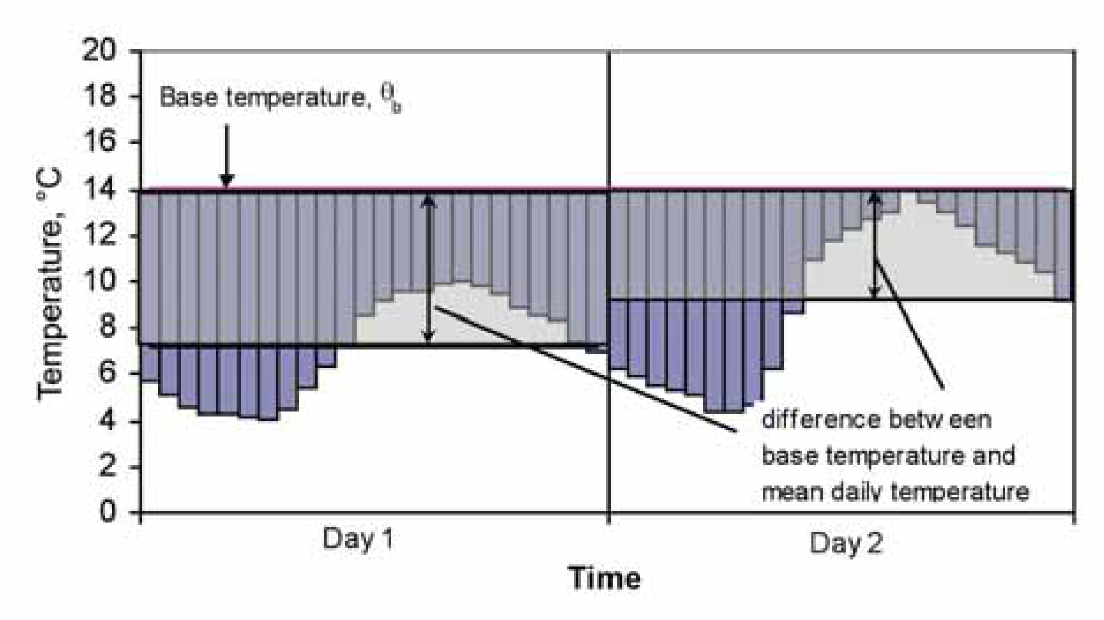

FIGURE 2.4: Basic definition of degree days [8]

T_{base} is base temperature. For Heating season, degree days is the area between T_{base} and T_A, while for cooling season degree days is the area between $T_A - T_{base}$.

Total envelope heat loss, including the ventilation and infiltration losses can be represented as product of total heat loss coefficient with the difference of zone and ambient temperature.

$$\dot{Q}_e = UA_o(T_z - T_A) \tag{2.25}$$

Over season, the energy needs to be supplied by heating system is the integration of the instantaneous heating energy. In performing the integration over season, the change of energy stored in the interior, is considered small relative to the total energy[22].

Neglecting the rate of change of energy storage, the heating energy need to be supplied from (2.16) can be written as,

$$\dot{L}_h = UA_o(T_Z - T_A) - (\dot{Q}_{sol} - \dot{Q}_g) \tag{2.26}$$

Furthermore, using the definition of balance temperature, the equation can be modified to

$$\dot{L}_h = UA_o(T_{basel} - T_A) \tag{2.27}$$

In the end, total heating energy demand over season, can be obtained by integrating the heating rate in equation above, assuming the heat transfer conductance is constant.

$$E_h = UA_o \int_0^{t_s} (T_{basel} - T_A)^+ \, \mathrm{d}t \tag{2.28}$$

2.6.3 Dynamic model : thermal resistance network

Thermal resistance network is one approach to describe the dynamic characteristic of building thermal condition. Using a physical approach, the heat transfer is described as an electric circuit. The temperature and the heat transfer are treated as voltage and current respectively. The element which can store heat such as concrete, is presented as capacitor, while the element with low capability for storing the heat, such as air, is described as a resistor. Further, each layer of wall or other composite element, can be represented as one or more resistor depending on its physical properties. When the element has big capacity to stored the energy, it is divide into a network of two or more resistor-capacitor(RC). Each layer is represented by a capacitor illustrating one lumped capacitance element.

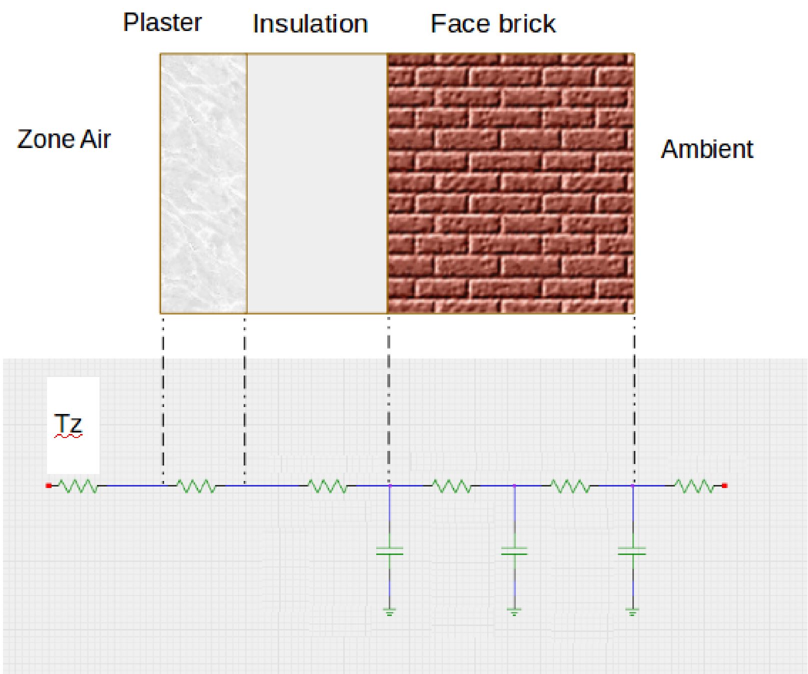

FIGURE 2.5: Typical wall of commercial building and its thermal resistance network model [22]

Figure 2.5 show the typical wall for commercial buildings, and its thermal resistance network representation.

The energy balance relation in every node can be write as

$$\frac{\mathrm{d}T_i}{\mathrm{d}t} = \left(\frac{T_{i-1} - T_i}{R_i Ci}\right) + \left(\frac{T_{i+1} - T_i}{R_{i+1} Ci}\right) \tag{2.29}$$

The temperature can be obtained as an integration of the equation, and the result is:

$$T_i(t) = T_{\text{initial}} + \int_0^t \left[\left(\frac{T_{i-1}(\tau) - T_i(\tau)}{R_i Ci}\right) + \left(\frac{T_{i+1}(\tau) - T_i(\tau)}{R_{i+1} Ci}\right)\right] \tag{2.30}$$

To solve the equation, boundary condition are needed. For wall the boundary condition are the solar-air temperature and the zone temperature.

Figure 2.6 shows the typical heat transfer mechanism in to an area inside the building, called *zone*. A zone can represent a a part of the room, a room, or even several rooms depend on various consideration. One consideration is the area. When the room is large, such as for sport hall, using multiple zone can make the representation more accurate. On the other hand, one zone model might still sufficient, depend on the purpose of the modeling, and which dynamic behavior intended to be examined.

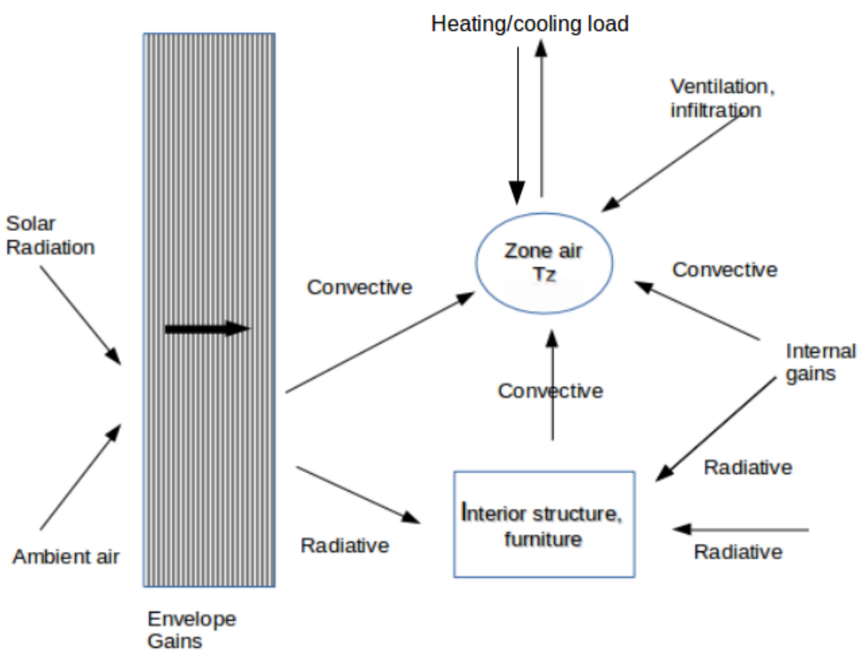

FIGURE 2.6: Heat flows in zone inside a building [22]

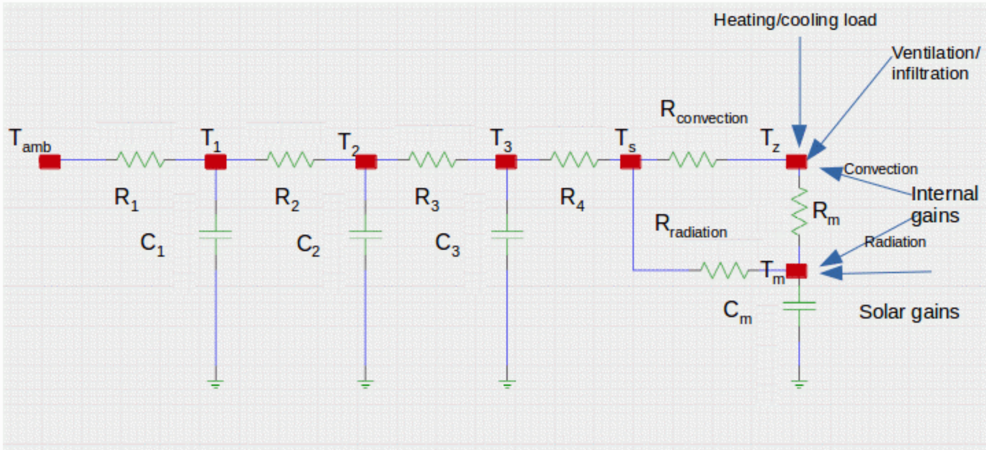

FIGURE 2.7: Heat flows in zone inside a building [22]

The thermal RC network for the zone in Figure 2.6, is given in Figure 2.7. The wall is represented as a series of three resistors and two capacitors(3R3C). T_1 is the outer surface of the wall, T_s is the inner surface of the wall, T_z is the zone temperature, and T_m is the thermal mass temperature.Node T_2 to T_3 and C_1 to C_3 in the picture represent the internal layer of the wall.

2.7 Conclusion

In this chapter, theory-related building thermal conditioning system is presented. Furthermore some methods in defining the model to analyze the system also included. This chapter is the basic theory for developing the model to evaluate the system in the next three chapters.

Chapter 3

Case Study

In this chapter the case study in this project is presented. This chapter divides mainly into three parts. The first part is about the weather data in Enschede, and Netherlands in general. The second part describes about the Zilverling building, in this case, the area, heat loss factor of building envelope, and the average occupancy of the building during teaching period. The third part presents the energy measurement data for Zilverling and the calculation of possible heat gain in Zilverling given the solar radiation, occupancy and electricity usage data.

3.1 Netherland weather data

The monthly average temperature in Table 3.1 obtained from Wunderground weather forecast website [29]. Furthermore more precise data in daily or hourly basis is available for downloading on Royal Netherlands Meteorogical Institute website [17].

In table 3.2 depicted the data of solar radiation in horizontal and vertical plane facing different orientation. This data is statistical data recalculated from global radiation for the Netherlands.

Month	$T_A(^oC)$
January	1
February	1
March	1
April	9
May	12
June	16
July	18
August	18
September	14
October	10
November	5
December	2.5
Average	9.41

TABLE 3.1: Enschede monthly average temperature [29]

Month	Plane								
	Hor.	N	NE	E	SE	S	SW	W	NW
January	43	39	39	39	40	42	41	39	39
February	117	48	48	58	105	143	126	73	49
March	254	89	94	130	198	264	244	168	99
April	373	123	138	194	257	306	306	242	160
May	503	186	211	277	302	307	357	352	267
June	574	230	235	298	321	316	379	419	344
July	504	192	207	262	287	292	338	348	277
August	489	161	196	289	347	367	372	333	240
September	295	106	109	153	212	274	295	248	162
October	166	65	65	86	153	203	174	105	66
November	63	33	33	36	58	73	64	40	33
December	35	22	22	22	22	22	22	22	22
Sum	3416	1337	1397	1844	2302	2608	2718	2389	1758

TABLE 3.2: Total global solar radiation in MJ/(m^2) on the horizontal plane and vertical planes for the Netherlands

3.2 Zilverling Building

Zilverling building is located in Hallenweg 19, 7522 Enschede. Being the office of the Electrical Engineering, Mathematics, and Computer Science faculty of the research institute CTIT, this building is chosen for study case, as the characteristic fit with major building in the university. This building has 5th floors, with 126 rooms per floor. The rooms are mainly uses as office, some rooms used as server and technician rooms.

This building heat comes from district heating of Enschede and distributes through the building by all water system heating. The heating mainly uses radiator, with minor usage of convector in the first floor (only for some area on the first floor). For cooling system combination of natural cold night air and phase changing material(PCM) are used to cool air which is transported through ducts to each floor to cool channels within the floor structure.

Solar radiation and building orientation Calculated by web application in [5], we found that the Zilverling orientation has 31^{o} deviation from the north. Having rectangle shape, each wall of building envelope considered perpendicular with each other.

This orientation becoming important to define the solar radiation in each wall. Having the data from Table 3.2, solar radiation in each wall of the building can be approximate using linear interpolation. This approximation is performed and the result is presented in Table 3.3

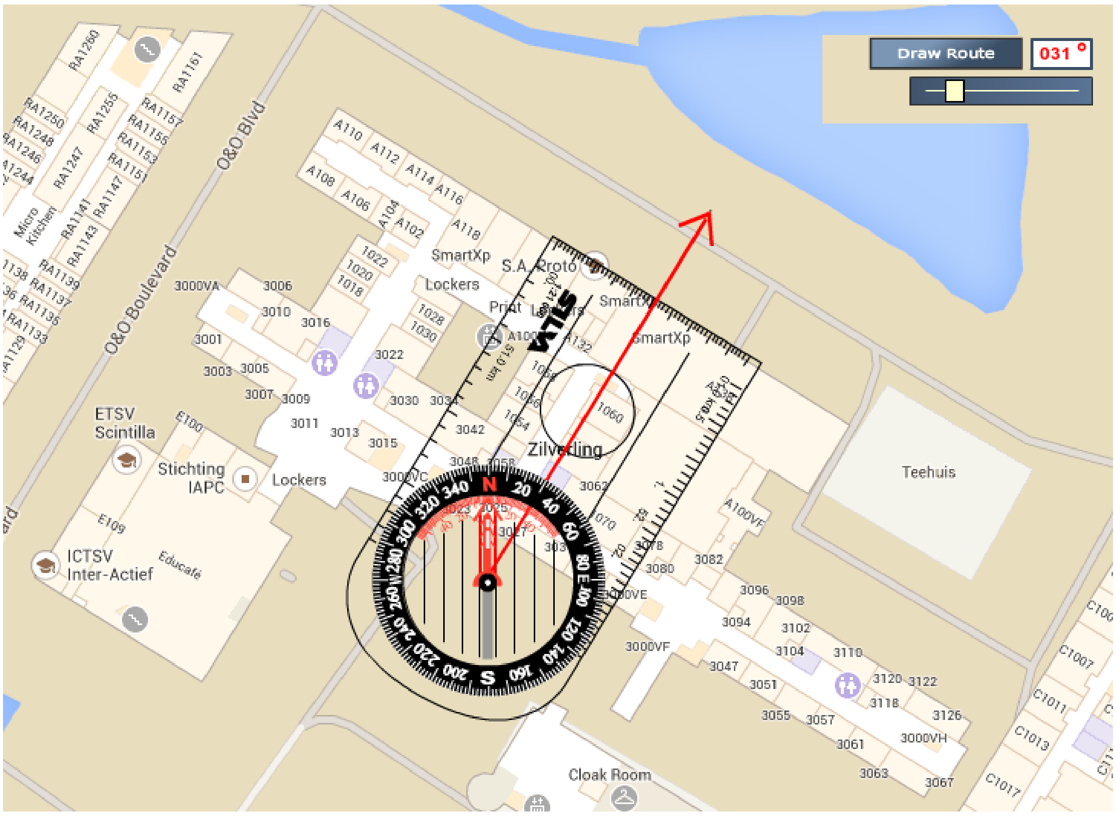

FIGURE 3.1: Orientation[5]

Month	Plane				
	Hor.	31^o from N	31^o from E	31^o from S	31^o from W
January	43	39	40	41	35
February	117	48	90	131	56
March	254	92	177	250	120
April	373	133	237	306	185
May	503	203	294	341	293
June	574	233	314	359	367
July	504	202	279	323	299
August	489	185	329	370	269
September	295	108	193	288	189
October	166	65	132	183	78
November	63	33	51	67	35
December	35	22	22	22	22
Sum	3416	1365	2160	2684	1954

TABLE 3.3: Total global solar radiation in each wall of Zilverling building in MJ/m^2

Occupancy Based on the university of Twente website, there are seven research groups resides in Zilverling building. Table 3.4 lists the research groups with the average number of people occupy their office during normal period, by means the teaching period.

Research Group	Average occupancy
Database	13
PS	20
CAES	35
HMI	30
SCS	50
DACS	20
FMT	34
DMMP	*18*

TABLE 3.4: The average occupancy in each research groups in weekday during teaching period

3.2.1 Thermal gain due to occupant

From ASHRAE standard, people working in office, with light degree activity, have metabolic rate 130 W for male, and 115 W for female, the sensible heat gain is 70 W and the latent heat gain is 45 W [14]. Given the average number of people occupy Zilverling on weekday during teaching period as stated in Table 3.4. the sensible heat gain is calculated by multiplying the number of person, the sensible heat gain produced, and the time length of occupancy

$$IHG_{occ} = people \cdot heat\ gain \cdot time_{occ} \tag{3.1}$$

IHG_{occ}, is internal thermal gain due to occupants, *heat gain*, is sensible heat gain from every person, and $time_{occ}$ is the time length of occupancy, in the office, the value is similar as work hour. Assuming there are 22 work days in average for every month, with work hours $8 hours/day$ and people only stay in the office during work hours, the calculation become,

$$IHG_{occ} = 220 \cdot 70\ W \cdot 22\ days \cdot 8\ h \cdot 3600\ s/h \tag{3.2}$$

$$= 9,76\ GJ \tag{3.3}$$

3.3 Heat loss factor in Zilverling

3.3.1 Building envelope

The area of Zilverling is calculated with some approximation. This is by means some part of it is measured manually such as the width of the window, the total wall area is recalculated based on the data drawing obtained from Facility Department archive, with approximation given the measured dimension of the window.

The U-factor which is related to the building material is approximate from the rule applied in the year when the building was built around 1992-1995 [23], that the R-value for concrete part of building envelope is 2.5 $m^2 \cdot K/W$ and the U-value for the window should be less than 4.2 $W/(m^2 \cdot K)$. separate from the concrete the U value for window is chosen based on data for double glass window, using aluminum frame with thermal break [19].

	Area(A) (m^2)	U (W/K)	UA (W/K)
Concrete(Wall+Roof)	3863	0.4	1545
Window	1597	3	4790

Table 3.5: Building envelope heat loss factor

3.3.2 Ventillation

There are 4 active ventilators installed and operated in the main building of Zilverling with different capacity of air flow rate. Each capacity of the ventilator is listed in Table 3.6

Ventilator	Flow rate (m^3/h)
AV3f	5060
AV3g	2400
AV3h	3000
AV3i	1875

TABLE 3.6: Air flow rate of ventilators installed in Zilverling

In the calculation of UA factor from ventilation, an assumption that those ventilators works in full power is used. This assumption is made, based on consideration that many natural ventilations sources exist. This is including window and small channel opening above every windows in the building. For the same reason the heat transfer through infiltration is not considered as separate factor, instead the amount of heat loss through infiltration is considering as a fraction of ventilation air flow, working in full power.

Recall the equation 2.15, and given the information of air specification, the result of heat loss factor through ventilation is depicted in Table 3.7

Air Density	1.2041 kg/m^3
Air scpecific Heat	1012 $J/(kg \cdot K)$
Air Flow Rate	12335 m^3/h
Heat loss from ventilation	15.03 MW/K

TABLE 3.7: Ventilation heat loss factor

3.3.3 Total heat loss factor

Based on the data explained above the heat loss factor for the main building of Zilverling is the summation of heat loss through, roof, wall, window and ventilation system. In the calculation, wall and roof are unified and called building concrete. This calculation is perform and the result is shown in Table 3.8

Heat loss factor of building concrete	1545 W/K
Heat loss factor of window	4790 W/K
Heat loss factor from ventilation	4175.2 W/K
Total heat loss factor	10.51 KW/K

TABLE 3.8: Total Heat Loss Factor (UA)

3.4 Measurement data

From our discussion with Mr. John Susebeek from UT facility department, we obtained the data of energy usage. The data available for Zilverling included, heating, electricity and water usage. For heating demand, assuming the excluded part of the building (Educafe, SmartXP lab and the office part for CTIT in the first floor) is weighted half amount of the load, the actual data received from the Facility Department is divided by 2.

Presented in Table 3.9, the monthly heating demand for main Building of Zilverling.

Month	Heating Demand (GJoule)	Month	Heating Demand (GJ)
jan-2013	384.76	nov-2013	256.31
feb-2013	330.05	dec-2013	263.70
mrt-2013	356.43	jan-2014	362.94
apr-2013	180.24	feb-2014	276
mei-2013	97.24	mrt-2014	200
jun-2013	43.17	apr-2014	109
jul-2013	9.85	mei-2014	80.5
aug-2013	32.62	jun-2014	58
sep-2013	87.63	jul-2014	15.5
okt-2013	156.27		

TABLE 3.9: Zilverling building heating demand monthly

Another important measurement data is electricity demand which is depicted in Table 3.10.

Month	Electricity Usage(kWh)
January	15819
February	19957
March	19037
April	18761
May	17875
June	17945
July	16035
August	15619
September	19100
October	19943
November	19551
December	3937.69

TABLE 3.10: Electricity usage of Zilverling building in years 2013

3.5 Possible heat gain

Given internal thermal gain due to occupant, the solar radiation to each wall, and the electricity demand of the building. The possible heat gain of the building can be calculated. Assume 100% of electricity demand turn to heat, the possible heat gain in the building over a year is calculated by adding the internal thermal gain due to occupants, electricity and solar radiation pass through the window gain. The result of this calculation is shown in Table 3.11.

Month	Solar radiation	Electricity	Occupant	Total heat gain
January	44.38	56.95	9.76	111.09
February	97.87	71.85	9.76	179.47
March	188.17	68.53	9.76	266.46
April	244.22	67.54	9.76	321.51
May	306.84	64.35	9.76	380.94
June	336.68	64.60	9.76	411.04
July	296.87	57.73	3.90	358.50
August	312.98	56.23	4.88	374.09
September	220.38	68.76	9.76	298.90
October	136.10	71.79	9.76	217.65
November	54.97	70.38	9.76	135.11
December	24.59	14.18	9.76	48.52

TABLE 3.11: Possible heat gain

Figure 3.2, shows the amount of possible heat gain and heating demand for Zilverling over years, based on Table 3.9 and Table 3.11.

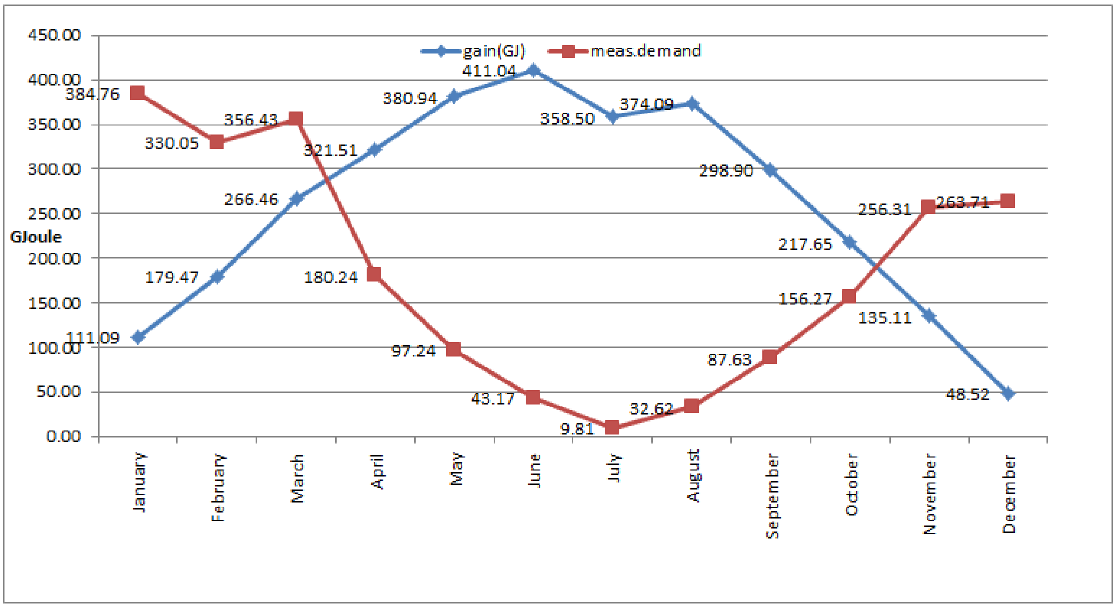

FIGURE 3.2: Comparison of possible heat gain, possible heat loss from degree day method, and heating demand measured by Facility Department

3.6 Conclusion

This chapter presents the data of the building, including calculation of solar radiation effect and thermal specification of the building. Furthermore the possible heat gain for Zilverling over years is calculated. This result is used as a basic data for developing and evaluating the model in the next chapter.

Chapter 4

Degree Day Model Calculations

In this chapter, the calculation for heating and cooling load, based on degree day model is presented. After obtained the total heating load over years, the result is compared with heating demand based on measurement data. Later on the heat loss factor is analyzed, to find the trivial suggestion for conserving the energy based on calculation in this static model.

4.1 Degree Days Model

From monthly average temperature in Table 3.1, monthly degree day for Enschede is calculated. The calculation perform separately for cooling and heating season, used vary base temperature from 15.5 ^oC to 18 ^oC.

4.1.1 Heating Season Degree Day

Recalled the explanation in Chapter 2,degree day model is calculated based on equation 2.18. The result presents in Table 4.1.

Month	$T_A[^oC]$	DDm $[day \cdot K]$ (for various T base)					
		$15.5\,^oC$	$16\,^oC$	$16.5\,^oC$	$17\,^oC$	$17.5\,^oC$	$18\,^oC$
jan-13	1	450	465	481	496	512	527
feb-13	1	406	420	434	448	462	476
mrt-13	1	450	465	481	496	512	527
apr-13	9	199	213	227	242	257	271
mei-13	12	120	134	147	161	175	190
jun-13	16	0	0	48	57	67	77
jul-13	18	0	0	0	0	0	0
aug-13	18	0	0	0	0	0	0
sep-13	14	69	79	90	102	115	128
okt-13	12	120	134	147	161	175	190
nov-13	6	286	301	316	331	346	360
dec-13	5	327	342	357	373	388	403
jan-14	6	296	311	326	342	357	373
feb-14	4	323	336	350	364	378	392
mrt-14	8	235	250	265	281	296	311
apr-14	12	116	129	142	156	170	184
mei-14	13	95	107	120	133	147	161

TABLE 4.1: Monthly heating degree-days for Enschede with different base temperature

4.1.2 Cooling Season

Using similar procedure cooling degree day is calculated based on equation 2.19, and the result is presented in Table 4.2.

Month	$T_A[^oC]$	DDm $[day \cdot K]$ (for various T base)					
		$15.5\,^oC$	$16\,^oC$	$16.5\,^oC$	$17\,^oC$	$17.5\,^oC$	$18\,^oC$
jan-2013	1	0	0	0	0	0	0
feb-2013	1	0	0	0	0	0	0
mar-2013	1	0	0	0	0	0	0
apr-2013	9	0	0	0	0	0	0
may-2013	12	0	0	0	0	0	0
jun-2013	16	15	0	0	0	0	0
jul-2013	18	78	62	47	31	16	0
aug-2013	18	78	62	47	31	16	0
sep-2013	14	0	0	0	0	0	0
okt-2013	12	0	0	0	0	0	0
nov-2013	6	0	0	0	0	0	0
dec-2013	5	0	0	0	0	0	0
jan-2014	6	0	0	0	0	0	0
feb-2014	4	0	0	0	0	0	0
mar-2014	8	0	0	0	0	0	0
apr-2014	12	0	0	0	0	0	0
may-2014	13	0	0	0	0	0	0
jun-2014	16	15	0	0	0	0	0

Table 4.2: Monthly cooling degree-days for Enschede with different base temperature

4.2 Analysis and comparison with measurement data

4.2.1 Heating demand

The comparison between heating demand from degree day calculation and the data measured by Facility Department shown in figure 4.1. This graph shows the comparison in monthly basis.

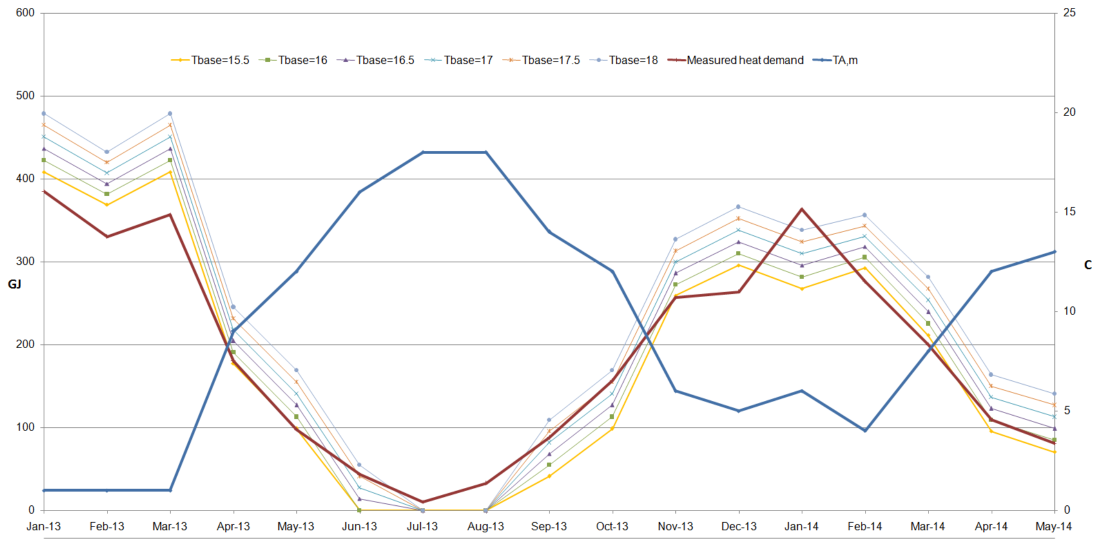

FIGURE 4.1: Monthly heating demand measurement data compare to degree days calculation

Calculated results show heating demand from degree day method is higher than measurement by facility department. This incident is likely to occur, since degree day method does not take the influence of controlling mechanism into account, such as when heating system is turned off during weekend and holiday period.

Based on the comparison, it can be concluded that in general the heating system of Zilverling is well maintained. The graph shows the demand follows the trend of statistical calculation with the Degree Day method. However, the graph shows a deviation in January 2014. In this month the ambient temperature is higher, therefore the heating demand is expected to be decreased. The model follow this rule, but measurement data show the opposite result.

Another different result found during summer period June-August. Based on the average temperature the heating system supposedly turned off during this period, however the measured data shows the building is heated by the system.

4.2.2 Cooling demand

For cooling season, using 18^oC as base temperature, will lead to no cooling demand at all for the whole years. Lower base temperature could be an option in evaluating cooling degree day.

Looking at the daily base temperature during summer in Enschede, the data shows the temperature is changing in wide range. Even during summer period, there are some days when the temperature is drop to around $11\,^oC$ then raise again to around

$22\,^oC$. Therefore further evaluation in daily basis should be performed to see the dynamics influence in cooling demand.

4.2.3 Analysis for heating and cooling demand in summer period

To find out the reason of the deviation of the measured data, further comparison between heating and cooling demand during summer period is investigated. Figure 4.2 shows measurement data for heating and cooling demand during this period in daily basis.

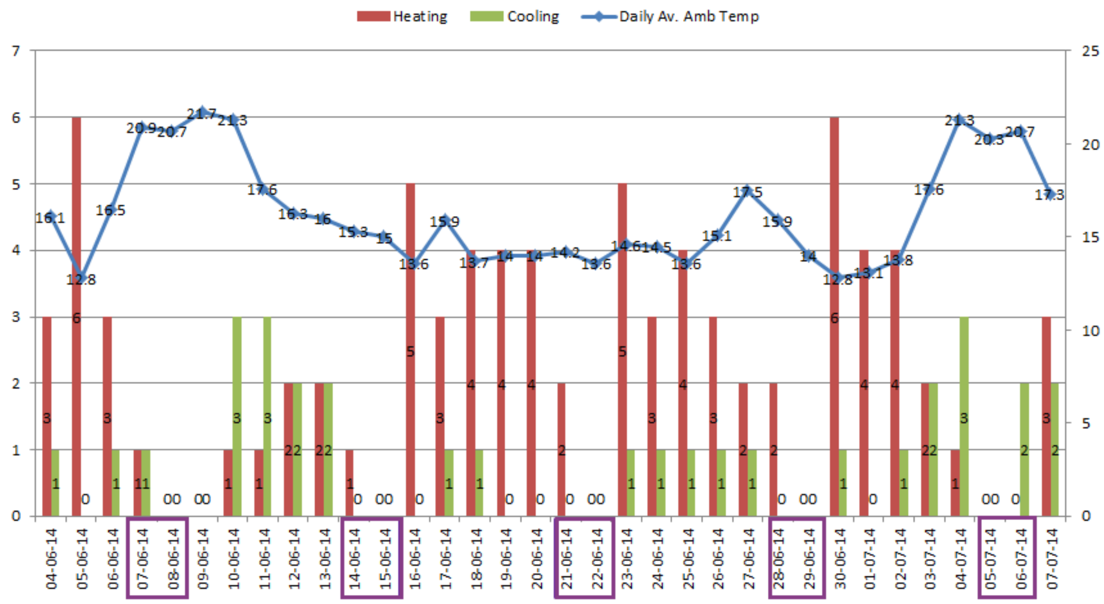

FIGURE 4.2: June-July heating and cooling demand measurement data

The value shows in the picture is measured in GJ. The purple box on the axis show weekend period.

The graph shows, the heating system is working in most of the time during summer period. Further checking daily consumption data, shows the heating system is turned on early in the morning to preheat the building. On Monday the heating system is turned on earlier, therefore high peak consumption is always exist on that day. It is also shows in many occasion when heating and cooling system is active at the same day, which is expected to be avoided.

4.3 Heat balance calculation

Recall heat balance description from Chapter 2, the heat balance in the building is calculated, using (2.17). Assuming the calculation is made for long period, the energy change $\frac{\mathrm{d}E}{\mathrm{d}t}$ is neglected, therefore the equation is reformed to

$$Heat\ Gain = \dot{Q}_{sol} + \dot{E}_g + \dot{L}_T \tag{4.1}$$

$\dot{Q}_{sol}$ is solar radiation, $\dot{E}_g$ is internal thermal gains which is internal gain due to occupant and electricity equipment which is represented by electricity demand data, and $\dot{L}_T$ is heating load which is represented by measured heating demand. In the other hand, heat loss is represented by equation:

$$Heat\ Loss = \dot{E}_{v,inf} + \dot{Q}_e \tag{4.2}$$

$$= Heat\ loss\ factor_{total} * (T_Z - T_A) \tag{4.3}$$

$\dot{E}_{v,inf}$ is heat loss trough ventilators as defined in section 3.3.2, $\dot{Q}_e$ is heat loss through building envelope. Assuming there are 22 working days every month, and the indoor temperature is set to be fix in 20 ^oC for 12 hours every day. The heat loss factor is calculated for monthly basis over a year, and the result is presented in Table 4.3

Month	T_A	Gain(GJ)	Loss (GJ)	Gain-Loss (GJ)
January	1	495.84	219.38	230.92
February	1	509.51	219.38	230.92
March	1	622.89	219.38	230.92
April	9	501.75	127.01	138.55
May	12	478.18	92.37	103.92
June	16	454.21	46.18	57.73
July	18	368.31	23.09	34.64
August	18	406.70	23.09	34.64
September	14	386.53	69.28	80.82
October	12	373.92	92.37	103.92
November	6	391.42	161.65	173.19
December	5	312.23	173.19	184.74

TABLE 4.3: Heat balance

Ideally, the heating system should not be active when natural heat gain is sufficient to replace the heat loss, which occurs during summer period. In the reality that condition is quite hard to achieve, since all calculations for defining the control of heating system is made based on estimation.

To evaluate the heating system, Figure 4.3 separate the heat gain factor to natural gain and active gain. From this picture, the comparison of heat loss to passive and active heat gain can be evaluated. The comparison shows, the amount of passive gain

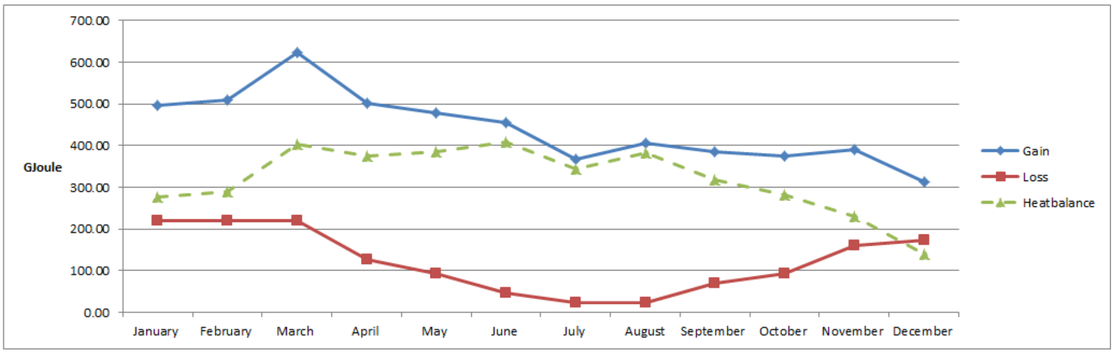

FIGURE 4.3: Comparison of possible heat gain, possible heat loss from degree day method and heating demand measured by Facility Department

in March to October is supposedly sufficient to replaced the heat loss and to maintained the indoor temperature steady at 20^oC.

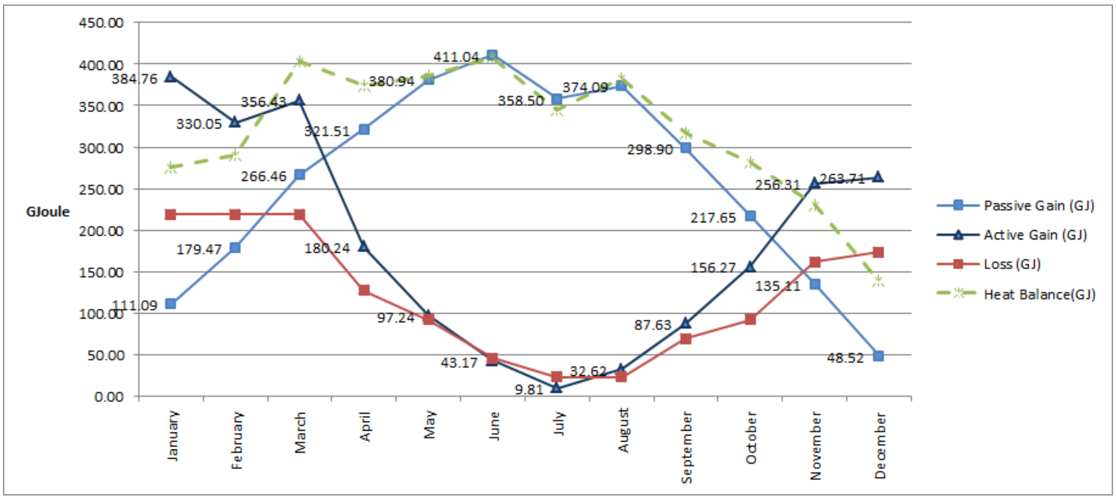

FIGURE 4.4: Comparison of possible heat gain, possible heat loss from degree day method and heating demand measured by Facility Department, differ the active and passive heat gain

The active heat gain, which is correspond to heating system behavior, in general, shows the expected result. By means active heat gain is decrease, when natural heat gain is increase. However further investigation needs to be perform to analyze whether the amount of active heat gain is acceptable or not, moreover to find the possible amount of energy that could be saved.

For this purpose, the evaluation should be conducted under dynamics condition. Including the change of weather in daily or even in hourly basis. This approach can also define the optimum time to preheat the building.

4.4 Heat loss component

The heat loss factor (UA) divide the heat loss mechanism of Zilverling into three major component shown in Figure 4.5.

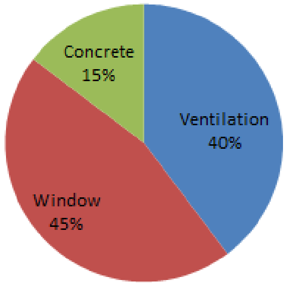

FIGURE 4.5: Heat Loss Component in Degree Days Calculation

From the model, the major heat loss comes from window, trivial suggestion will be to do replacement with lower U value window. However other further calculation should be perform since the replacement will also influence the solar gain.

4.5 Conclusion

In this chapter the static model to evaluate the heating system is presented. The evaluation shows, in general the system is well maintained, however to find the possibility for saving energy, more detail evaluation need to be performed. In the next chapter, the dynamic model is presented.

Chapter 5

Dynamic Model Development, Thermal Network Approach

In this Chapter the system is evaluated under dynamic condition. The method used is thermal resistance network approach. This approach is taken to further analyze the dynamic behavior of the building. This approach will take the influence of ambient temperature, solar gain, and heating energy given by the radiator to the indoor temperature.The purpose to do this investigation is to see the direct impact of those three factors and get some insight about the method to save more energy.

5.1 Thermal resistance network method

Recall the explanation of thermal resistance network in Chapter 2. The heat transfer mechanism and thermal condition in a zone inside the building can be represented as RC network. In this research, the representation from [21] is used.

The model consist of two storage element, one represent the thermal mass c_m and the other represents the interior c_i. The thermal mass c_m included structural element of the building such as floor and separate wall. On the other hand the interior storage element c_i represents the furniture, and air inside the building. r_a represents the building envelope resistance.r_i represents the resistance between thermal mass and interior.

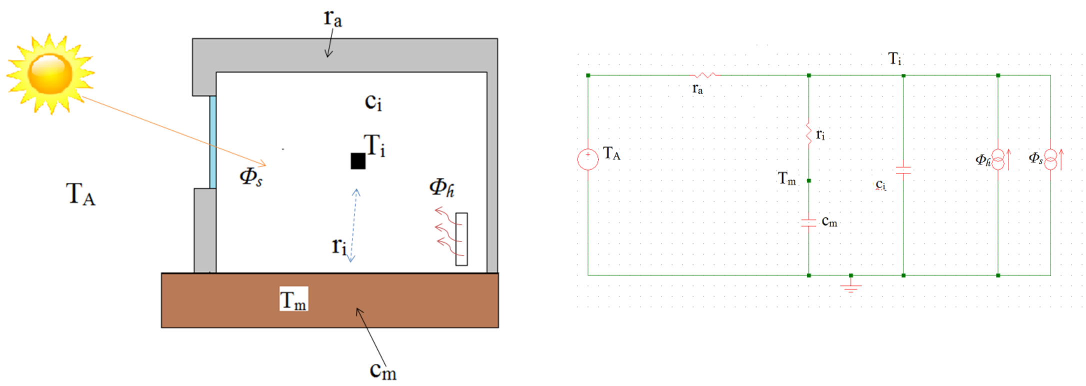

FIGURE 5.1: Two time constant model for heat dynamics of a building [21]

In equation, the model in Figure 5.1 is represented as:

$$\begin{bmatrix} \frac{\mathrm{dT_m}}{\mathrm{dt}} \\ \frac{\mathrm{dT_i}}{\mathrm{dt}} \end{bmatrix} = \begin{bmatrix} \frac{-1}{r_i c_m} & \frac{1}{r_i c_m} \\ \frac{1}{r_i c_i} & -\left(\frac{1}{r_a c_i} + \frac{1}{r_1 c_i}\right) \end{bmatrix} \begin{bmatrix} T_m \\ T_i \end{bmatrix} + \begin{bmatrix} 0 & 0 & \frac{A_w p}{c_m} \\ \frac{1}{r_a c_i} & \frac{1}{c_i} & \frac{A_w(1-p)}{c_i} \end{bmatrix} \begin{bmatrix} T_A \\ \phi_h \\ \phi_s \end{bmatrix} \tag{5.1}$$

T_m defines the thermal mass temperature, while T_i defines the interior temperature. A_w is the windows area, p is the fraction of the solar gain which absorbed by thermal mass. For the input T_A represent ambient temperature, ϕ_h is the heating supply, and ϕ_s is the solar gain. The interior temperature later can be obtain using the principle to get the capacitor voltage from its current.

$$T_i(t) = \frac{1}{C} \int_{t_0}^{t} I(\tau)\mathrm{d}\tau + T_i(t_0) \tag{5.2}$$

Recall the heat loss factor present in the building. The modification is made to the model by adding the ventilation factor. The further circuit and equation is become as follow

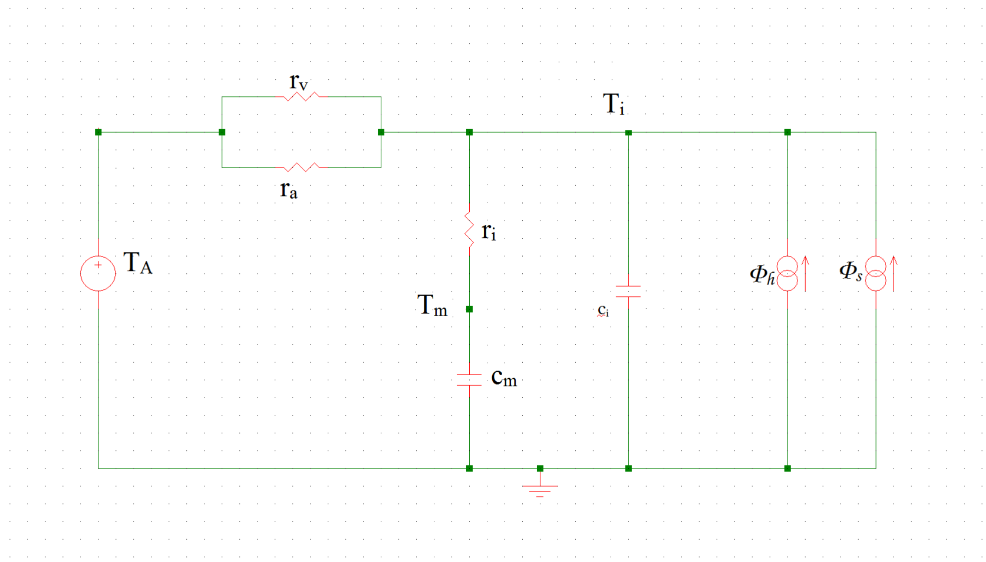

FIGURE 5.2: Two time constant model for heat dynamics of a building [21]

In equation, the model in Figure 5.1 is represented as:

$$\begin{bmatrix} \frac{\mathrm{dT_m}}{\mathrm{dt}} \\ \frac{\mathrm{dT_i}}{\mathrm{dt}} \end{bmatrix} = \begin{bmatrix} \frac{-1}{r_i c_m} & \frac{1}{r_i c_m} \\ \frac{1}{r_i c_i} & -\left(\frac{1}{r_a c_i} + \frac{1}{r_i c_i} + \frac{1}{r_v c_i}\right) \end{bmatrix} \begin{bmatrix} T_m \\ T_i \end{bmatrix} + \begin{bmatrix} 0 & 0 & \frac{A_w p}{c_m} \\ \left(\frac{1}{r_a c_i} + \frac{1}{r_v c_i}\right) & \frac{1}{c_i} & \frac{A_w(1-p)}{c_i} \end{bmatrix} \begin{bmatrix} T_A \\ \phi_h \\ \phi_s \end{bmatrix} \tag{5.3}$$

From its original source in [21], the model is build to represent the building which have light structure in the outer part (envelope), and heavy structure in the inner part. This model give the good result [21] in describing the dynamic behavior of the represented zone. Considering Zilverling has similar structure with the represent zone in [21], this model is chosen.

5.2 Model development and simulation

This section will explain the development of the model, the procedure of the simulation and the result obtained.

5.2.1 Model development

The value of each component is calculated and approximated using some known physical properties. r_a is calculated from the building envelope properties include wall, roof, and window given in Section 3.3. As r_a represent the total building envelope, its value is defined by:

$$\frac{1}{r_a} = \frac{1}{r_{a_{concrete}}} + \frac{1}{r_{a_{window}}} \tag{5.4}$$

c_m value is obtained by calculating the heat capacity of separate wall and floor in the building. For each element the heat capacity is calculated by equation:

$$c_m = (c_{p_{wall}} \cdot \rho_{wall} \cdot V_{wall}) + (c_{p_{floor}} \cdot \rho_{floor} \cdot V_{floor}) \tag{5.5}$$

where c_p is specific heat of particular material, in this case the material of wall or floor, ρ is the density, and V is the volume. The total heat capacity of thermal mass is the sum of the heat capacity of wall and floor.

$$c_m = c_{m_{separatewall}} + c_{m_{floor}} \tag{5.6}$$

For c_i, we assume that the furniture and all equipments inside the building is represented by 500-2500 kg of wood per room. Then the value is calculated with equation:

$$c_i = (\frac{weight\, of\, wood}{room} \cdot \rho_{wood} \cdot c_{p_{wood}} \cdot number\, of\, room\, in\, building) \tag{5.7}$$

r_i which is represented the convection mechanism between thermal mass surface with interior element is defined by equation 2.6 in Chapter 2. The value of interior convection coefficient given by ASHRAE is $8.29\, W/m^2K$ [4]

In building system, thermal mass is treated as passive energy source. This is due to the fact that the thermal mass has capability in preserved the energy and release it slowly to the zone when the zone temperature decreases.

5.2.2 Procedure of simulation

After define the value of each component the simulation is carried out. With the purpose to find out the effect of ambient temperature, solar gain, and heat supply given by radiator to the zone temperature. The first step of this simulation is to obtain realistic behavior for zone temperature given the listed input and the specified component value with the purpose to reconstruct the current situation. During the simulation the value of some element is tuned accordingly. The change of first calculated value to the value that used in simulation is shown in Table 5.1.

The modeling and simulation is performed in Matlab using *ODE45* function and Microsoft Excel. The input are hourly ambient temperature solar gain data from KNMI [17], and heating supply data which obtained from UT Facility Department.

Component	First value	Tuned value	unit	changed asumption
r_a	1.578×10^{-4}	1.578×10^{-4}	K/W	-
r_i	5.86×10^{-6}	5×10^{-6}	K/W	increase the contact surface between interior and interior element
c_m	2.57	2.57	$MWhour/K$	-
c_i	0.07	0.4	$MWhour/K$	increase the number of room and mass per room
r_v	2.4×10^{-4}	2.4×10^{-4}	K/W	increase the air flow rate

Table 5.1: the value of each component used in simulation(UA)

The model is evaluated for every month condition from January to June 2014. however is it found that there is some inconsistency in the recorded heat supply data in during last ten days in January, May, and the first week of June. Therefore, this first step only analyze is the zone temperature during the months that do not have the data problem.

The first simulation to defined model, shows that the interior temperature is stable in the range of $18\,^oC$ to $20\,^oC$ in February, and increased as the ambient temperature also higher during summer.

In the second step several procedure is applied to the heating supply, to find the possibility in controlling it and conserve the energy. In this step, the simulation procedure applied are:

1. Scenario 1 : Weekend off, in this scenario we nulled the heat supply during weekend and monitor the zone temperature. The focus is if the zone temperature during work hours in weekdays is affected by this scenario.

2. Scenario 2 : In addition to weekend off, the heat supply before 3 a.m is also nulled. this procedure is taken to evaluate the effect of changing the time to preheat the building.

3. Scenario 3 : In this scenario a simple Algorithm 1 is applied to the heating system.

Algorithm 1: Simple controlled algorithm applied in the simulation. t_i is represented the preheat time

```
input  : Day, hour (t), and zone/interior temperature(T_i)
output: Heat supply to the building, (φ_h)

while weekdays do
    if Monday then
        t_1 = 2
    else
        t_1 = 4
    end
    if t ≥ t_1 then
        if T_i ≤ lower bound set point_1 then
            φ_h = full power
        else if T_i ≥ upper bound set point_1 then
            φ_h = 0
        else
            φ_h = half power
        end
    else if 8 ≤ t ≤ 19 then
        if T_i ≤ lower bound set point_2 then
            φ_h = full power
        else if T_i ≥ upper bound set point_2 then
            φ_h = 0
        else
            φ_h = half power
        end
    else
        φ_h = 0
    end
end
```

5.2.3 Result

The result of the all the procedure listed in the previous section is given in the graph of zone temperature for every month.

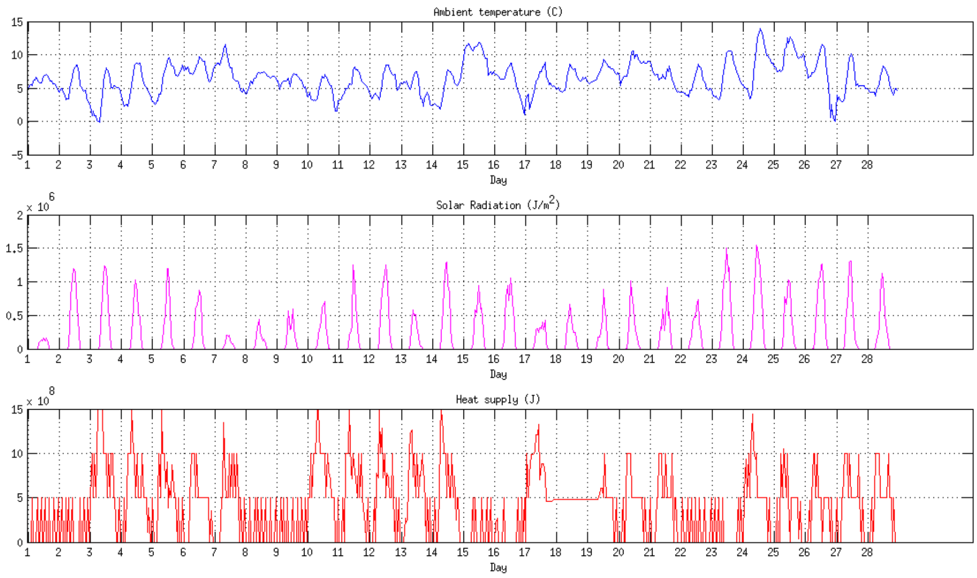

FIGURE 5.3: Ambient temperature, solar radiation and measured heat supply in February

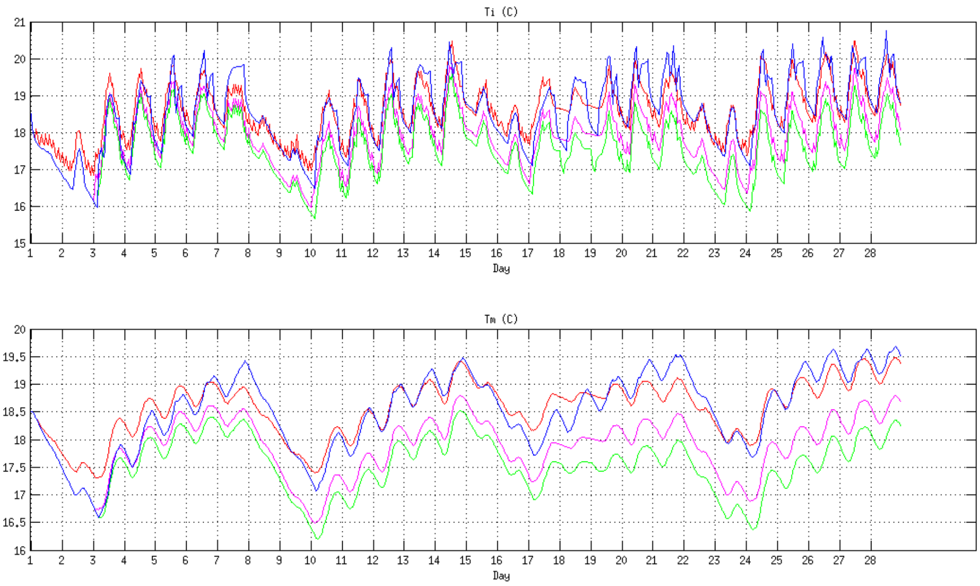

FIGURE 5.4: T_i and T_m in February, (red: the first simulation, magenta: Scenario 1, green: Scenario 2, blue: Scenario 3)

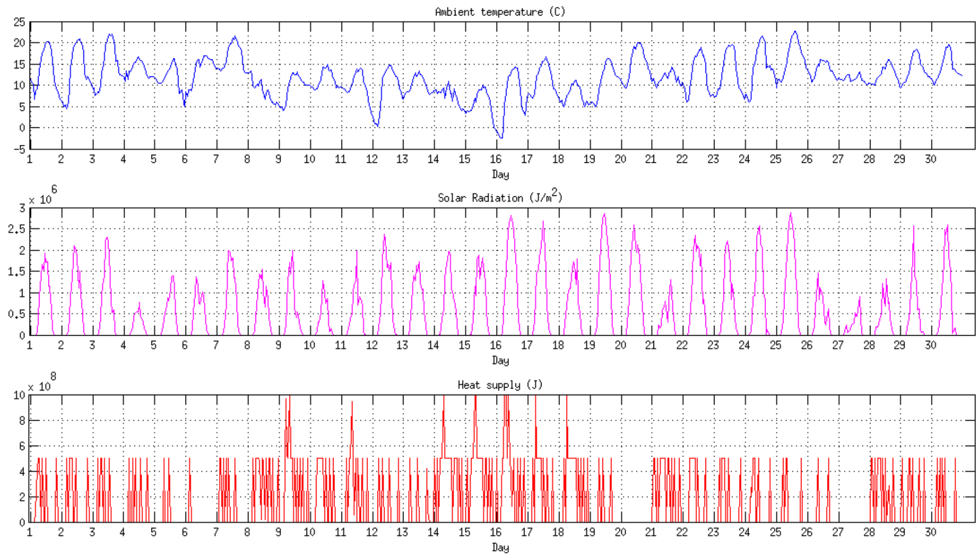

FIGURE 5.5: Ambient temperature, solar radiation and measured heat supply in April

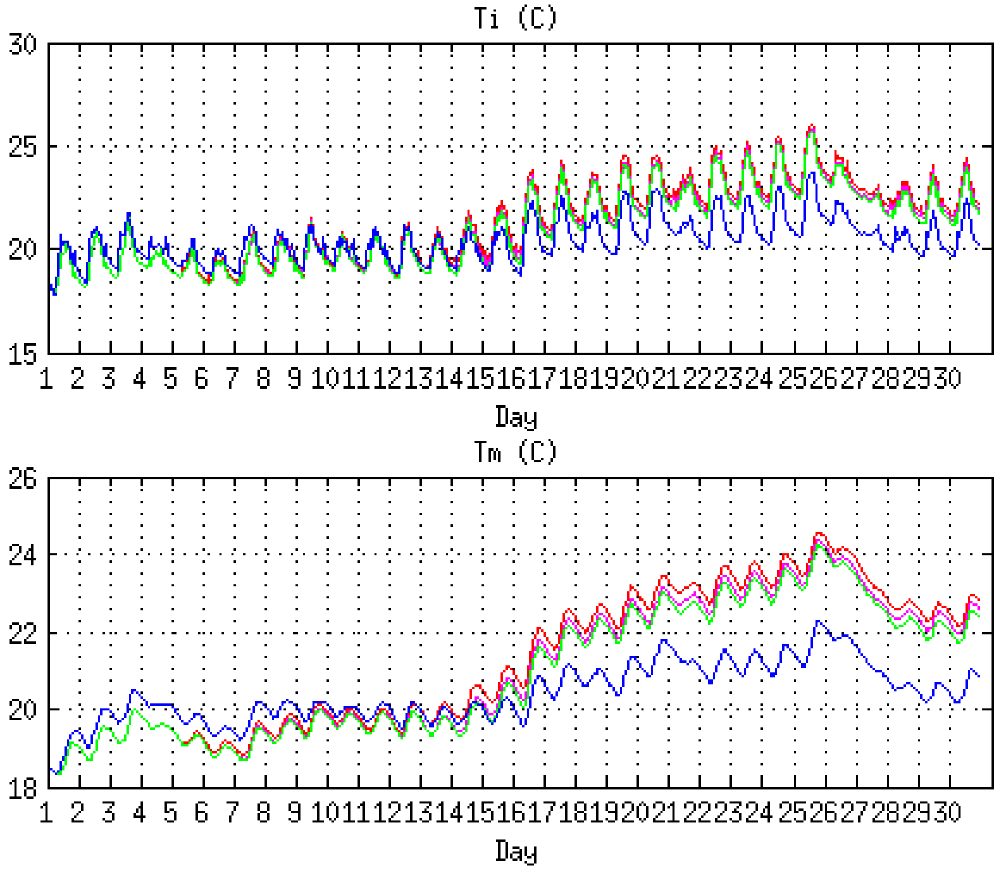

FIGURE 5.6: T_i and T_m in April, (red: the first simulation, magenta: Scenario 1, green: Scenario 2, blue: Scenario 3)

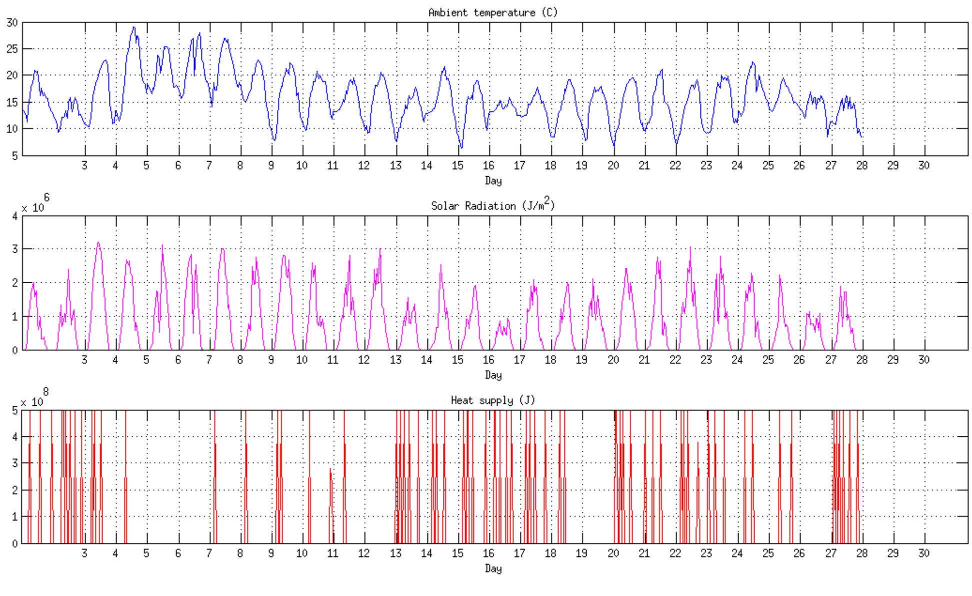

FIGURE 5.7: Ambient temperature, solar radiation and measured heat supply in June

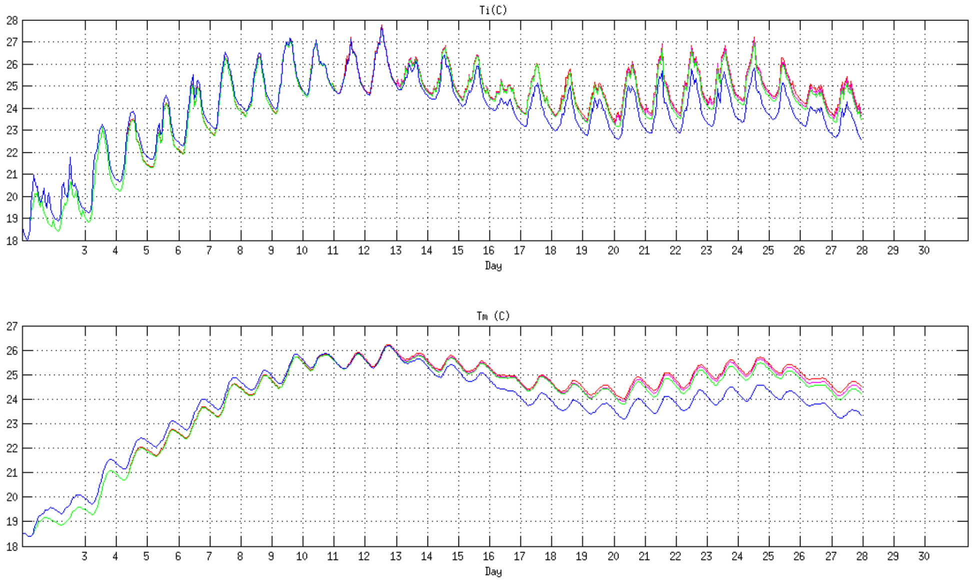

FIGURE 5.8: T_i and T_m in June, (red: the first simulation, magenta: Scenario 1, green: Scenario 2, blue: Scenario 3)

Based on the simulation, the reconstruction of current heat control maintain zone temperature is in the range above 18 ^oC during work hours. The temperature is decrease during off hours and weekdays, but the heat supply able maintain the temperature to be stable during work hours, weekday, from 9 a.m to 18 p.m.

The applied procedure to control the heat supply have different effect to zone temperature depend on the season. apply procedure 1 and 2 during winter (February) give significant effect to lower zone temperature during during work hours after this period especially in Monday. On the other hand applying procedure 3 give slightest lower temperature than the original condition in the beginning of every week, however the control manage to reach the set point later on and maintain the temperature above 18^o.

During warmer period (April- June), controlling the heat supply by applying all three procedure does not give significant impact to the zone temperature during work hours. This is due to the greater solar radiation and higher ambient temperature in these period. This reason indicates heat supply by while maintain the zone temperature during work hours, is possible during this warmer period.

In detailed the heat demand/supply to building, based on those three simulation is given in Table 5.2

Month	Heat Supply based on various scenario (GJ)			
	current heat supply	procedure 1	procedure 2	procedure 3
January	363	324	309	363
February	276	251	238	276
March	200	172	163	167
April	109	102	102	64
May	80	68	64	60
June	58	55	52	17

Table 5.2: Heat supply based on various scenario

Overall the applied control procedure satisfy the purpose to reduce the heating demand. However this procedure does not give significant result in the winter period (February). On the other hand applying this procedure is possible during warmer period (April-June)

In June another scenario to turned off the heater totally is applied. This simulation is carried out, to address the issue in Section 4.2 when cooling and heating system active at the same time.

The result of this simulation shown that the zone temperature in June is naturally high due to high ambient temperature and solar gain. Therefore, propose to turned off the heater during summer period is reasonable.

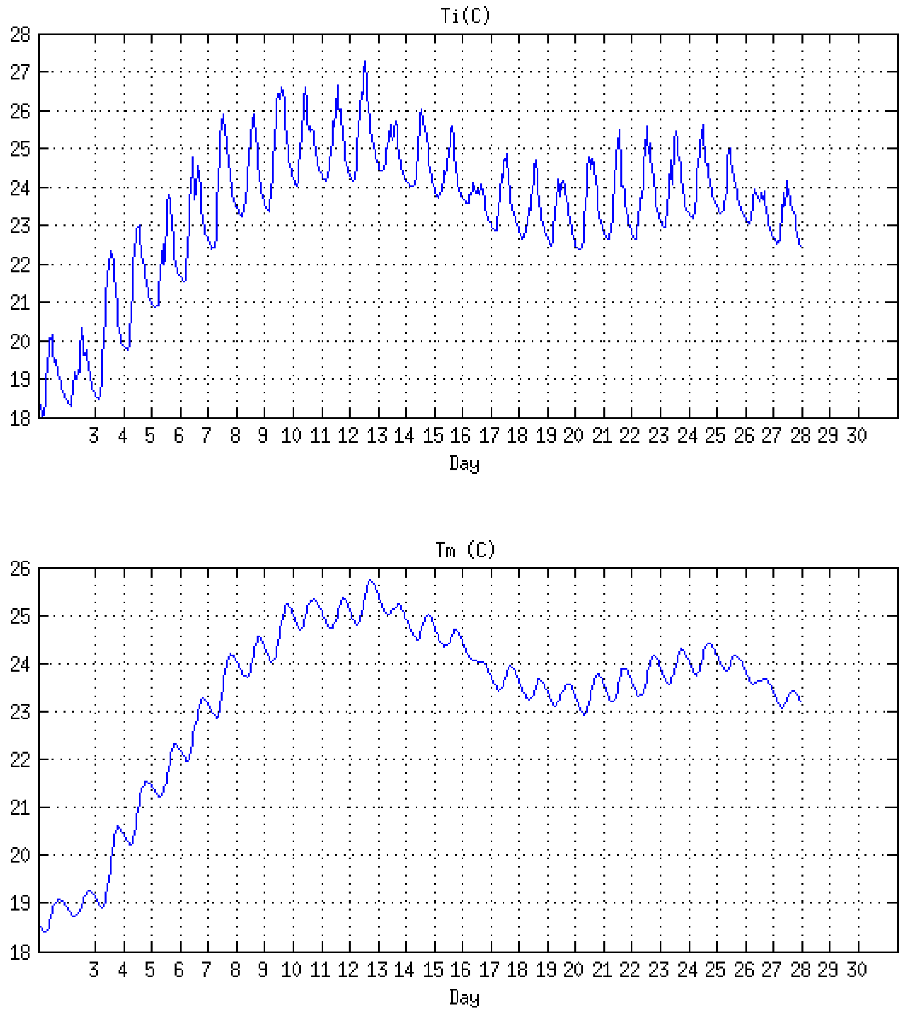

FIGURE 5.9: T_i and T_m in June with heater off

5.3 Conclusion

In this chapter, the dynamic model to evaluate the heating system is presented. The simulation shows the model is quite realistic in defining the zone temperature. The reconstruction of current condition shows that the building zone temperature is maintained above 18 ^oC during work hours. Furthermore, scenarios with different control algorithm are simulated. The first issue to address is turn off the heating system on the weekend. This scenario significantly influence the zone temperature during during winter period, while in warmer period or summer the reduction to the heat supply does not give significant effect to the zone temperature during work hours.

To sum up, it is possible to reduce heating energy during the summer period. Furthermore, turning off the heater during summer is also possible, without giving too much effect to the condition during work hours.

However, it must be stressed that the model is only accurate when parameters are identified from dynamic measurements or detailed building simulation. The current estimation, though inaccurate can be used to give insights in the possibility to safe energy by applying better control algorithms for the heating and cooling system.

Chapter 6

Recommendation

The simulation of static and dynamic model carried out in Chapter 4 and 5 give some indication of the opportunity to conserve the energy. In this chapter some recommendations based on those results are given.

6.1 Heating off in the summer

Based on simulation result depicted in Figure 5.9 summer season turned off the heating system does not indicate negative impact. Based on the simulation, the zone temperature will eventually increase naturally. Therefore turning off the heating system during summer is found reasonable

6.2 Weekend Control

Based on simulation of dynamic model in the warmer period(April-June) turning off the heater does not give a significant effect to the zone temperature during working hours, Figure 5.6 and Figure 5.8. Furthermore, this simulation give the result of saving between 7% and 16% energy, see Table 5.2.

6.3 Applied integrated controller

Analyzing the result of two statics calculation methods performed, led to the indication that exist some controlling issue during summer period. This conclusion comes from the both comparisons data between degree day method result and the measurement data also heat balance calculation and the measurement data.

Further investigation in daily basis comparison as shown in Figure 4.2, also shows that there are few days which the heating and cooling system working at the same time.

Additionally simulation to dynamic model, found that applying simple control algorithm give quite significant amount in energy saving Table 5.2. Therefore, more energy saving is expected by applying more proper integrated controller to the system. Furthermore, it should also control the cooling demand, so both heating and cooling system is not working at the same time.

6.4 Building Refurbishment

In additional to heat demand calculation base on statistical data, the static model also give some information about the heat loss components and the possible heat gain component in the building. The information given in Section 4.4 indicate the opportunity of energy saving from replacing the window.

Windows replacement can be one solution to conserve the energy, and reduce the heat loss during winter. Lower U factor window with high shading coefficient could be the solution. This can be solve either with adding other plane to window (triple glazing) or adding insulation layer, such as HR or low emission (Low-E).

Low-e coatings reflect heat in one both directions. Since the addition of a low-emissivity coating adjacent to an air space has the effect of lowering the U-factor (that is, raising the R-value) of the air space, a low-e coating helps slow heat transfer from the interior to the exterior during the winter, and also helps slow heat transfer from the exterior to the interior during the summer.

This replacement could be different in each side of the building considering the sun position. Being in a cold climate with high heating demand, windows with a high SHGC, especially on the south side is preferable, to have as much solar gain as possible.

6.4.1 Energy profile with window replacement

Single Glazing has a U-value of 5, older double-glazing about 3 and new modern double glazing has U-value of 1.6. This modern window improvements achieved through optimization of the window cavity, the use of low emissivity coatings, inert gas to fill the gap, and using aluminium spacers or cold bridges [26].

Recalculating the heat loss factor and solar heat gain for window based on different window specified in Table 6.1, giving some illustration of heat loss and gain percentage. Figure 6.1, show the comparison of heat loss and solar gain, for different type of window comparing to the current installed window.

Window Description	Window Type	U value	Glass light transmit-tance	effective g-value / SHGC
Hard coat Low e DGU, air filled	A	2.0-2.2	0.75	0.66
Hard coat Low e DGU, argon filled	B	1.8	0.75	0.66
Soft coat Low e DGU, argon filled	C	1.6	0.79	0.57
Soft coat Low e DGU, argon filled warm edge (Securestyle 'A' rated)	D	1.4	0.79	0.57
Triple (incl 2 x hard coat low E) argon filled	E	1.2	0.66	0.51
Triple (incl 2 x hard coat low E) argon filled warm edge, insulated frame	F	1.0	0.66	0.51
Triple (incl 2 x soft coat) argon filled warm edge, insulated frame	G	0.8	0.69	0.45

Table 6.1: SHGC for various types of glazing [see e.g., [12, 20]]

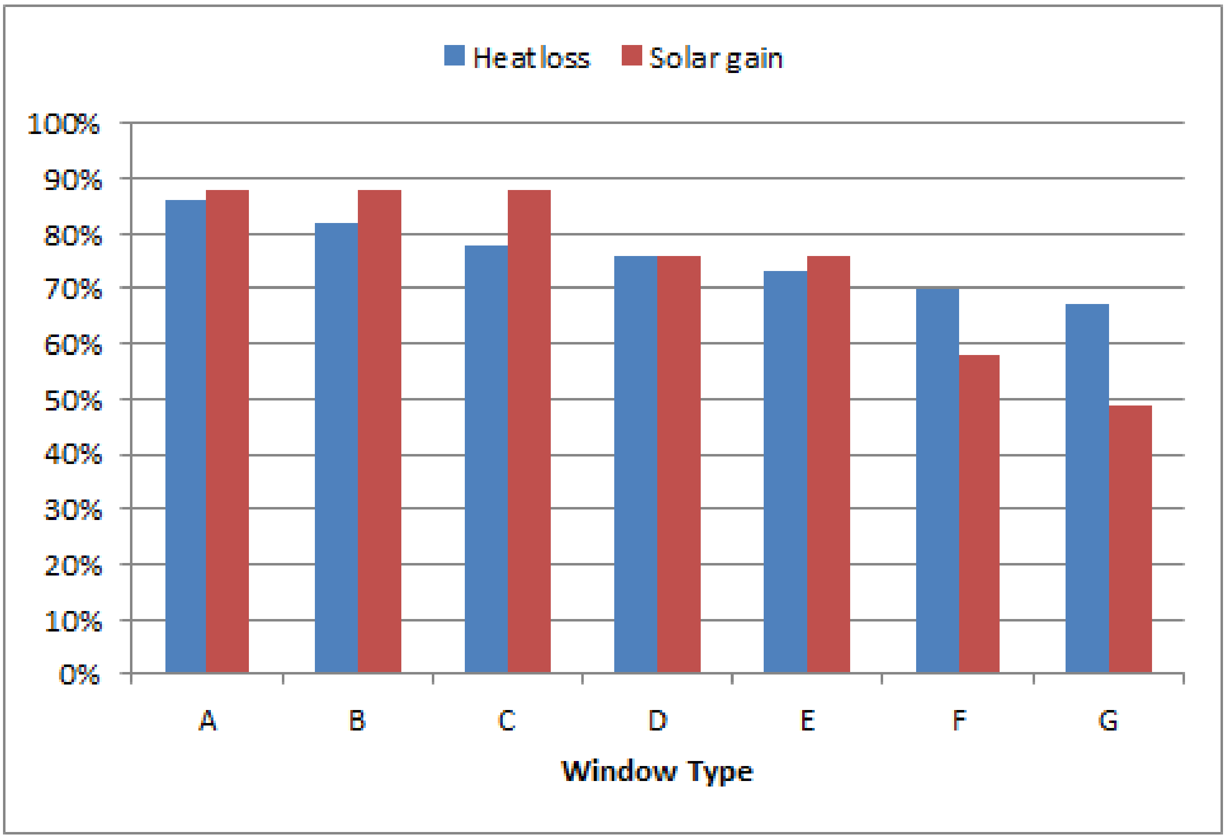

Figure 6.1: The change of heatloss and solar gain due to window replacement

Chapter 7

Conclusion and Further Research

In this chapter the conclusion of this research is presented. Furthermore, some issues that need to be investigated further are given for further research.

7.1 Conclusion

During the research some studies of heating system in Zilverling have been carried out. This study is mainly about the heating system, and the building energy performance related to heating system. To evaluate the system, static and dynamic model are used.

The static model presented in Chapter 4 illustrates the building thermal behavior in long time period. Based on evaluation on degree day model is it found that in overall the building is well maintained. This conclusion is obtained from the fact that measured heating demand follows a statistical calculation over a year. However some different result is found during summer and in January 2014. The degree days method shows there is no heating demand during summer (June-August), see Table 4.1 which is replaced by the demand of cooling, see Table 4.2, this issue is further investigate in dynamic model.

Besides heating demand calculation, the degree day method also gives information about the portion of heat loss component in the building which is dominate by heat loss to the window and ventilation system in this research, Figure 4.5. Furthermore, the static heat balance simulation over a year also been carried out. This simulation give the information about the component of heat loss and possible heat gain in a year, Figure 4.3.

Investigation in dynamic model carried out during this research evaluated the thermal behavior of the building in shorter unit period (hour) and introducing thermal mass concept. The model chosen in this simulation is based on model developed in

[21]. This model evaluated the effect of ambient temperature, solar heat gain, and heating supply to zone temperature.

The simulation in reconstruct the current condition using heating supply from measured data shows the zone temperature is maintained in the range of 18 ^oC to 20 ^oC in the winter (February) and which is increased in the later months due to the increasing of solar gain and ambient temperature.

Some simple algorithms applied to control the heat supply to the building, to find out the effect of reducing the energy supply to the zone temperature. Based on the simulation it is shown that the reduction of heating supply during winter give a direct effect in lower interior temperature. Applied some control mechanism to turn off the heating in the weekend caused more energy needed to preheat the building on Monday, before the working hour period, to maintain the zone temperature in acceptable range during work hours. This result indicate that is quite hard to applied some reduction to the heat supply while maintaining the zone temperature in acceptable range during winter, Figure 5.4. However applying this control mechanism period while maintaining stable zone temperature is found possible during warmer period (April), Figure 5.6. Furthermore the idea of turning off the heating during summer is also found to be valid, Figure 5.9.

Some recommendations to save the energy based on the simulation result are given in Chapter 6. However, as mentioned in the conclusion of Chapter 5 that the model is only accurate when parameters are identified from dynamic measurements or detailed building simulation. The current estimation, though inaccurate can be used to give insights in the possibility to safe energy by applying better control algorithms for the heating and cooling system.

7.2 Further Research

To further evaluated the heating system behavior in the building the investigation in dynamic model could be carried out further. The modification of the value used in each component to get more realistic behavior in interior temperature could be one of the next step. The other option is by decreasing the time step of simulation.

Other further investigation is about validating the model. Two approaches are possible to meet this purpose. The first is by using more detailed physical information of the building, then define the heating demand. For this purpose the building energy simulator such as TRNSYS or EnergyPlus is available. The second one is in reverse method by using model identification which is also used in [21]. In this method the building characteristic is identified from the precise heat measurement data and recorded interior temperature.

After the validation step, further research is to implement the control algorithm in the real system, and further monitoring the heating supply and demand in the building.

Bibliography

[1] International Energy Agency. Faqs: Energy efficiency. http://www.iea.org/aboutus/faqs/energyefficiency/, June 2014.

[2] Ashrae. *2013 Ashrae Handbook: Fundamentals (Ip & Si)*. Amer Society of Heating, 2013.

[3] Peder Bacher and Henrik Madsen. Identifying suitable models for the heat dynamics of buildings. *Energy and Buildings*, 43(7):1511–1522, 2011.

[4] Y.A. Çengel, A.J. Ghajar, and M. Kanoğlu. *Heat and Mass Transfer: Fundamentals and Applications*. McGraw Hill Higher Education, 2011.

[5] Barcelona Field Studies Centre. Zilverling building orientation. http://googlecompass.com/full-screen-map.htm?lat=52.239119510201434&lng=6.85701018436375&mType=0&pano=0&traffic=0&zol=20&pn=1, June 2014.

[6] RTP Company. Rtp company introduces smart plastics for bluetooth standardt. http://www.rtpcompany.com/rtp-company-introduces-smart-plastics-for-bluetooth-standard/, May 2014.

[7] Newport Corporation. Introduction to solar radiation. http://www.newport.com/Introduction-to-Solar-Radiation/411919/1033/content.aspx, May 2014.

[8] Tony Day. *Degree-days:theory and application*. The Chartered Institution of Building Services Engineers, 222 Balham High Road, London SW12 9BS, September 2006. Available at http://www.degreedaysforfree.co.uk/pdf/TM41.pdf.

[9] NL Agency NL Energy and Climate Change. Dutch climate policy:local challenge supported by the national goverment. http://www.agentschapnl.nl, May 2010.

[10] Concerted Action EPBD. Towards 2020 nearly zero-energy buildings. http://epbd-ca.eu/themes/nearly-zero-energy, May 2014.

[11] D. G. Erbs, S. A. Klein, and W. A. Beckman. Estimation of degree-days and ambient temperature bin data from monthly-average temperatures. *Ashrae Journal*, 25:60–65, 1983.

[12] DG Environment-G2 European Commission. Green public procurement : Windows technical background report windows, glazed doors and skylights . Technical report, European Commission, DG Environment-G2, 2013. Available at http://ec.europa.eu/environment/gpp/pdf/windows_GPP_background_report.pdf.

[13] Directorate-General for Climate Action. The 2020 climate and energy package. http://ec.europa.eu/clima/policies/package/index_en.htm, May 2014.

[14] ASHRAE Handbook Fundamental. Si-edition. *American Society of Heating, Refrigerating and air-conditioning Engineers, Inc., Atlanta*, page 18.4, 2013.

[15] Health and Safety Excecutive. Thermal comfort. http://www.hse.gov.uk/aboutus/index.htm, June 2014.

[16] Gerben Hieminga. Saving energy in the netherlands. Technical report, ING Economics Department, 2013. Available at http://www.ing.nl/Images/EBZ_ING-Saving_Energy_in_the_Netherlands-May_2013_tcm7-134961.pdf?id=20130529104701.

[17] Royal Netherlands Meteorogical Institute. Daily weather data of the netherlands. http://www.knmi.nl/climatology/daily_data/download.html, 2014. [Online; accessed July,17 2014].

[18] International Energy Agency, 9 rue de la Fdration, 75739 Paris Cedex 15, France. *Lessons Learned from The Energy Policies of IEA Countries*, 9 2009.

[19] Edwin Kort. Aan welke eisen moeten mijn kozijnen voldoen als ik ze vervang? http://www.ekbouwadvies.nl/bouwbesluit/energiezuinigheid/vervangenkozijnen.asp, 2014. [Online; accessed July,17 2014].

[20] Secure Style Windows Trade Ltd. Triple glaze vs double glazing. http://www.secure-style.co.uk/index.php/products/triple-glaze-vs-double-glazing, 2014. [Online; accessed July,17 2014].

[21] H. Madsen and J. Holst. Estimation of continuous-time models for the heat dynamics of a building. *Energy and Buildings*, 22(1):67 – 79, 1995.

[22] J.W. Mitchell and J.E. Braun. *Principles of Heating, Ventilation, and Air Conditioning in Buildings*. Wiley, 2012.

[23] Nederlands Normalisatie-instituut. Nen 1068:1991. thermische isolatie van gebouwen - rekenmethoden. http://www.nen.nl/NEN-Shop/Norm/NEN-10681991-nl.htm, August 1991.

[24] Dr. Sarma Pisupati. Mechanisms of heat loss or transfer. https://www.e-education.psu.edu/egee102/node/2053, June 2014.

[25] John Susebeek. Energy coordinator at university of twente. personal communication.

[26] TheGreenAge. Triple glazing is it worth it? thegreenage.co.uk/triple-glazing-is-it-worth-it/, 2013. [Online; accessed July,17 2014].

[27] H. C. S. THOM. The rational relationship between heating degree days and temperature. *Monthly Weather Review*, 82(1):1–6, 1954.

[28] The Engineering ToolBox. Cooling Loads - Latent and Sensible Heat latent and sensible cooling loads to consider in design of hvac systems. http://www.engineeringtoolbox.com/latent-sensible-cooling-load-d_245.html. Accessed: 2014-03-10.

[29] Weather Undergound. Enschede average weather by month. http://www.wunderground.com, July 2014.

[30] R.P. van Leeuwen, J.B. de Wit, J. Fink, and G.J.M. Smit. Thermal storage in a heat pump heated living room floor for urban district power balancing effects on thermal comfort, energy loss and costs for residents. Submitted, 2013.