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Optimal Use of Excess Energy from an Oversized SWH

Kathmandu Metropolitan City Scenario

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The final year project aimed to quantitatively analyse the space heating potential from excess energy of an oversized SWH system and its impact on thermal comfort. The thesis also aimed to uncover an optimal alteration of the building envelope to maintain a steady thermal comfort during the winter.

The final year project was based on a sample building, a typical representation of the building stock in the KMC, studied for its heating requirement and SWH system overproduction. The heating supplied from the excess energy of overproduction of the SWH system was quantitatively analysed to determine changes in operative temperature and heating demands. Nine building envelope modifications were simulated to establish an optimal modification alternative able to maintain the indoor thermal comfort of the heated space throughout the winter.

The heating supplied increased the operative temperature slightly and reduced the number of heating requirement days. Although the supplied heating was deemed insufficient to maintain the thermal comfort in the heated zone throughout the simulated period, with strategic building envelope modifications, the operative temperature was maintained at a desired level of thermal comfort throughout the winter. The findings could work as a frame work for experimentation of space heating in the KMC, and can be further studied together with other heating systems.

Keywords	SWH, space heating, thermal comfort, heating demand and building envelope.

Contents

1 Introduction

Solar water heating (SWH) systems are popular among the residents of Kathmandu metropolitan city (KMC). SWH system is primarily used for domestic hot water production for bathing and laundry in the residential buildings. With solar irradiation available in abundance throughout the year, interest in solar thermal collector installation is growing. A SWH system can adequately deliver the daily hot water demand of residential buildings in KMC. [1.]

Contemporary residential blocks in the KMC are found to have lower thermal performance than traditional residential blocks. Dense and compact form of urbanization has significantly obstructed the solar penetration in most residential buildings in KMC. The buildings are mostly made with concrete and bricks, lean walls and no insulation. This could undermine the thermal comfort in most of the buildings. During the winter season, the temperature inside the buildings plunge, requiring additional heating. [2.]

Usually, the installation of SWH system is based on an empirical method, determined by the size of a family. The installations are often oversized to ensure sufficient production. Moreover, a larger system is, in many cases, cheaper per unit price than a smaller system. [3.] Like in most of developing nations clean water supply is a scarce in the KMC. Hence, the populace is very wary of excessive usage. Hence, actual per person consumption is a lot smaller than the standardized quantity of 60-90 litre/day [4]. Consequently, overproduction is common in most instalments.

This thesis aims to uncover the potential of utilising the excess energy of overproduction of a SWH system to heat the living space during the winter months. The possibility to use the excess energy to heat spaces such as a kitchen or living room, even for a few hours a day in the morning or evening, can curtail space heating requirements and, simultaneously, improve the thermal comfort of residential buildings in the KMC.

Furthermore, the thesis looks at the potential of modifying the building envelope to maintain the thermal comfort in heated spaces throughout the winter. An optimal modification is searched.

In order to analyse the potential of using the excess energy from a SWH system for space heating and its impact on the thermal comfort of a building, the thesis collects weather data, looks into a case building, does a quantitative analysis of SWH system overproduction and heating demands, then, a simulation is done of the building with heating and evaluation of the results. Finally, simulates the building with various building envelope modifications to determine a desirable alternative.

2 Background

2.1 Kathmandu Metropolitan City

KMC is located at 27°22’ North and 85°20’ East, standing at an elevation of about 1,400 meters above the sea level. It is the urban core of the Kathmandu valley which encompasses three districts, Kathmandu, the capital city, Lalitpur and Bhaktapur. The Kathmandu district has 10 municipalities and one metropolitan area, the KMC. Spread across an area of 49.45 square kilometres, the KMC is subdivided into 32 wards (local unit) as shown in figure 1. The metropolis is culturally diverse, embracing various ethnicities, sects, religions and languages, boasting a rich cultural heritage of nearly 2000 years. [5.]

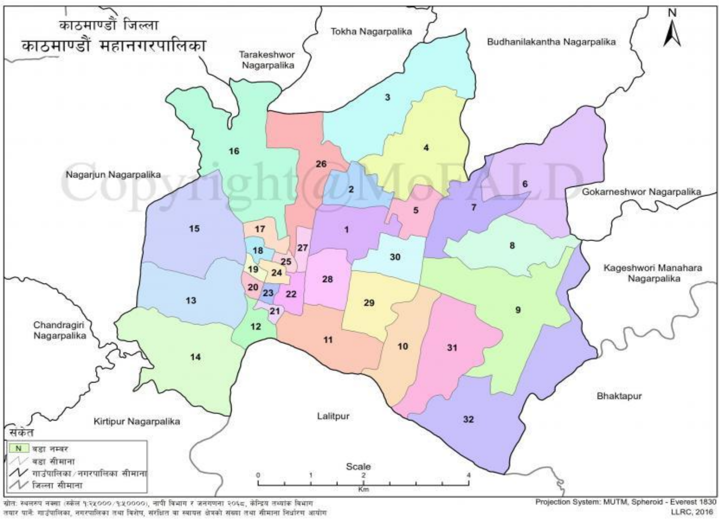


Figure 1. GIS map of Kathmandu metropolitan city [6].

KMC is the largest urban agglomeration in the entire nation with close to a million residents accounting for almost one-fourth of the urban population of Nepal [5]. There are a quarter of a million households in the region with an average family size of 3.84 [7]. Half of the dwellings are reinforced concrete structures, one-third of them are brick, cement and stone structures. The remaining are mud houses and other traditional houses. Concrete structures clearly dominate the urban construction and their number is increasing rapidly after the devastating earthquake of 2015. About one-third of the dwellings in the region are privately owned by the residents living in them, just a little under two-thirds are owned by landlords. [7.]

2.2 Solar Water Heating System

A SWH system is a set of devices put together in order to utilise the energy from the sun to heat water for various residential and industrial uses. In a residential use, SWH system is used to heat water for bathing, washing, cooking, cleaning and drinking. There are various types of SWH technologies, hence a diverse range of SWH systems are available. A typical SWH system in the KMC consists of a solar collector, tank storage, plumbing pipes, cold water storage, frame and, occasionally, a pump. The SWH system is installed in such a way that the water in the heater gets refilled as it is used, by the application of gravity in most cases. Thus, is automatic and self-regulating. The hottest water is automatically served and, in the presence of steady supply for refill, no manual interference is required. [4.] The working principle of a gravity fed system is illustrated in figure 2 below.

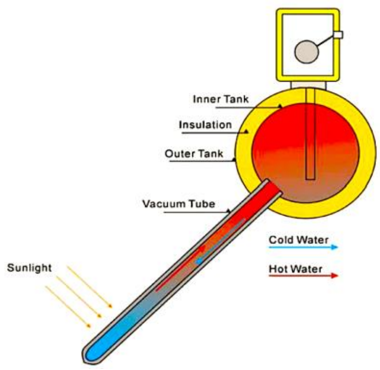


Figure 2. Working principle of a typical SWH system in KMC [3].

The KMC has more than three decades of experience in using SWH. Cornelius Suchy writes in his article Nepal's solar hot water scene from 2002, "Standing on one of the rooftops in Kathmandu you can actually see them everywhere." Cornelius cites a 1977 study by the secretariat of the water and energy commission of Nepal to tell that, 2000 SWHs are installed nationwide annually. [8.] Tri et al. found high satisfaction rate of SWH installations among households. In the same study, 97.2 percent of the respondents replied that they had installed SWH system primarily for bathing purposes. [1.]

An estimated 200 workshops manufacturing SWH system in the nation depicts the huge demand for such systems. In 2003, Tri et al. reported that an estimated thirty thousand households had installed SWH system, of which, about eighty percent were installed within the Kathmandu valley. [9.] A 2004 study by Tri et al. estimates 47,000 units being installed within Kathmandu valley [1]. Nationwide, 185,000 SWH systems had been installed by 2009 [10]. A typical SWH system installation in a residential building in an urban KMC is shown below in figure 3.

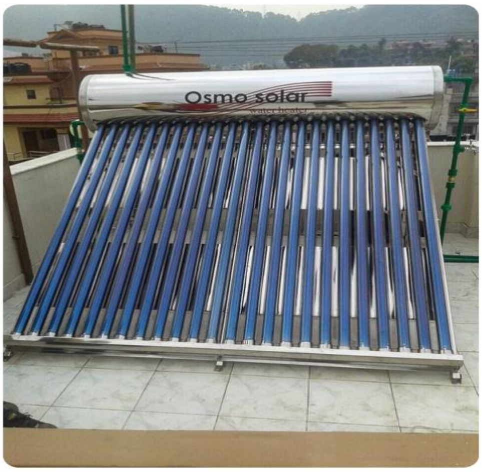


Figure 3. Typical SWH system installation in KMC [3].

On average, the storage capacity of a SWH system installed in the Kathmandu valley is 270 litres [1]. Flat plate collectors have been the most installed systems but they are being replaced by evacuated tube systems. Nowadays, new installations are mostly evacuated tube systems. As the performance of an evacuated tube is higher and its costs lower than those of a flat plate collector, they are more appealing to households. Evacuated tubes imported from China are affordable and popular in the KMC. [11.]

2.3 Components of a SWH System

2.3.1 Solar Collector

A solar collector is the most important component of a SWH system. The energy from the radiation is concentrated and absorbed directly by the working fluid that is to be heated. Likewise, the energy could also be absorbed, and then circulated by heat transfer fluid thus by re-releasing / transporting the heat to the working fluid to be heated. In simple terms, the solar collector either heats the working fluid directly, or it heats the heating fluid which, in turn heats the working fluid. Typically, solar collectors are stationed in a place with minimal shading and with an optimal angle of inclination, facing south to capture the maximum energy for longer hours. [4.]

Solar collectors can be categorised into two sub groups, concentrating and non-concentrating. A concentrating collector, in order to increase the radiation flux, has usually a large concave reflective surfaces to intercept and focus the sun's beam into a much smaller receiving area. The non-concentrating collector on the other hand, has the same area for both the interception and absorption of solar radiation. Their position is permanently fixed. Thus, they are unable to track the sun. In regular household usage only, non-concentrating collectors are installed. [12.] Hence, only the non-concentrating collectors are discussed further. Generally, three different types of non-concentrating solar collectors are used. In general application there are mainly three different types of non-concentrating solar collectors are used, flat plate collector, evacuated tube collector and compound parabolic collector.

A flat plate collector is usually used for domestic hot water and space heating. It is made up of an absorber plate, a heat transfer component, glazing and insulation. [13.] It contains a dark absorber plate of high absorptivity under a glazing surface, and it is insulated both underneath and around to prevent heat loss. The absorber plate absorbs energy then it transfers the energy to the carrier in the fluid tubes to be carried for either use or to storage. The collector absorbs both direct and diffuse radiation and has a low working temperature of 30°C - 80°C. It is robust and can withstand the impact of weathering. It is simple in design and construction, hence it has an affordable upfront cost. Furthermore, the lack of moving parts in the system reduces the need and cost of maintenance. [14.]

Evacuated tube collectors are suitable when the required working temperature is high, between 50°C and 200°C, and the climate is cold, windy and cloudy. An evacuated tube collector consists of rows of parallel transparent glass tubes. Each tube, in turn, consists of an inner and outer glass tube separated by a vacuum. The inner tubes are coated with a selective coating with 95% absorptivity and 5% emissivity that facilitates the absorption of solar energy and constrains the radiative heat loss. The vacuum between the layers of glass suppresses the heat loss due to conduction and convection, thus increasing their efficiency. [13.] Evacuated tube collectors absorb direct radiation and can absorb diffuse radiation very effectively as well. It has a high efficiency at low incidence angles thus giving them an advantage over flat plate collector in a day-long performance.

Compound parabolic collector uses mirrored surfaces. By the use of mirrored surfaces, the solar energy is concentrated on a receiver. The heat transfer fluid absorbs the heat as it flows. The mirrored surfaces can only absorb direct radiation, and on sunny days their output can reach a much higher temperature (60°C-240°C) than that of other collectors. They are generally used for commercial and industrial purposes, for instance steam generation for electricity production. [14.]

2.3.2 Storage Tank

The storage tank is an important part of a SWH system. In a passive system the tank is placed above the collector. The design and construction of the storage tank plays an important role in determining the heat loss from the system. As the storage tank is exposed to the ambient temperature which is lower than that of the tank, the tank’s heat loss increases proportionally. To efficiently store hot water, the tank has to be made of a lower surface area and should be insulated adequately. [4.]

In general, the storage tank of a passive system has an inlet for cold water, a gate to prevent the mixing of hot and cold water, an outlet, a pressure release valve and integrated electric heating. The electric heating provides backup heating during cloudy days. [15.]

2.4 Types of SWH system

The passive SWH system relies on the natural convection due to the difference in densities of hot and cold water for circulation in the system. Which eliminates the need for an electrical pump for circulation. The passive systems are easier to install, cost less and require minimal or no maintenance. However, they are comparatively less efficient, and problems with overheating and freezing are often noticed. [16.] Thermal systems such as flat plate collectors or evacuated tube collectors with the plumbing and storage designed on the principal of natural convection can be categorised as a passive system.

An active SWH system makes use of one or more pumps in circulating the hot water. The active systems are expensive compared to passive systems and require regular maintenance. An active system is efficient, and offers an array of advantages over a passive system, like the freedom in the design of the system, and the location of storage tank. An active system also offers an increased control over the performance of the system. [16.]

3 Methodology

In the thesis, weather data of the KMC is studied. Climate data of the subject area is studied to define the time frame for which space heating is required. Parameters are defined to set the study period. Once the time frame is decided, solar irradiation for the specified period is studied in detail. Solar irradiation data is then listed for calculations to follow.

In the thesis, the majority of existing buildings in the KMC are represented by a simulated building model that is designed in ArchiCAD based on the statistics of building stocks in the KMC from 2011. The features of the building envelope are adopted from the national building code of Nepal and the statistical data from the census of the year 2011. A SWH system is selected for the building and system specification of the SWH system is discussed in detail chapter 5.2.

The SWH system of the simulated building is analysed quantitatively for overproduction, and the thermal quality of the envelope is also analysed. A detailed calculation of the SWH system production is performed theoretically. Overproduction is defined when the system temperature exceeds the set limit for domestic hot water consumption. After the calculation of excess heat on a daily basis for the entire heating period, heat output for each month is calculated. Then, daily heating power for each month is calculated followed by the quantitative analysis of thermal quality of the building. PHPP V8.5 excel sheet is used to calculate the heating demand. The thermal properties of the building elements are determined, and then, the heating demand is calculated. Heating demand is calculated on a monthly basis to obtain the heating demand for each heating month. Heating demand is calculated and presented as a thermal quality of the building envelope.

In order to evaluate the effect of added space heating, evaluation parameters are set in chapter 7. Thermal comfort in relation to the change in operative temperature, and heating demand are set as indicators of performance. The indoor thermal comfort is defined, and a standard based on the available literature for the location is set. Reference heating demand is defined. Likewise, interpretation of change in heating demand from the reference model is defined. Furthermore, zone classification is also carried out for strategic heating of the spaces.

Finally, two sets of simulation are carried out. The first simulation is carried out to study the thermal performance of the building without the added heat. The result thus obtained is set as a base model to analyse and compare the effect of added space heating. The results obtained from the simulation are studied and a strategic location for space heating is selected for further simulation. After the selection of heating space, a second set of simulation is made with all parameters identical to the base model while adding specific heat to the selected zone for the simulated month. Once the second set of simulation is completed, the results are analysed and compared with the base model from the first set of simulation. The parameters compared are the change in thermal comfort (operative temperature) and heating demand. Any increase in the operative temperature is interpreted as success, and the degree of change is set to determine the effectiveness of the measure.

In order to maintain the thermal comfort in the heated zone, various modifications of the building envelope, together with the specified heating are studied. Insulation is added to various building elements like roof, walls and floors to modify the building envelope. Simulations are performed to study the effect of the added insulation. Various alternatives are studied to find an optimal combination of heating and modifications to maintain the thermal comfort of the heated space. An optimal modification alternative is determined based on the required insulation area, heating demand and thermal comfort in heated zone and its adjacent zones.

4 Weather Data

4.1 Climate in Kathmandu

The KMC has a temperate climate with dry winters and hot summers. The air temperature can reach as high as 31°C in the summer and can drop briefly down to -2°C at nights in the winter. However, below zero temperatures are rare. In general, the yearly average temperature is 17°C. The minimum average temperature of 9.7°C is observed in January. The maximum average temperature of 23.5°C is observed in June. [17.] In figure 4, reprinted from the Meteorological forecasting division (MFD) [18], the temperatures from the 27th of October 2018 till the 11th of April 2019 are shown when the air temperature is below 20°C. However, the thesis only looks at the time from November to February when the ambient temperature remains below 18°C, and there is a need for space heating.

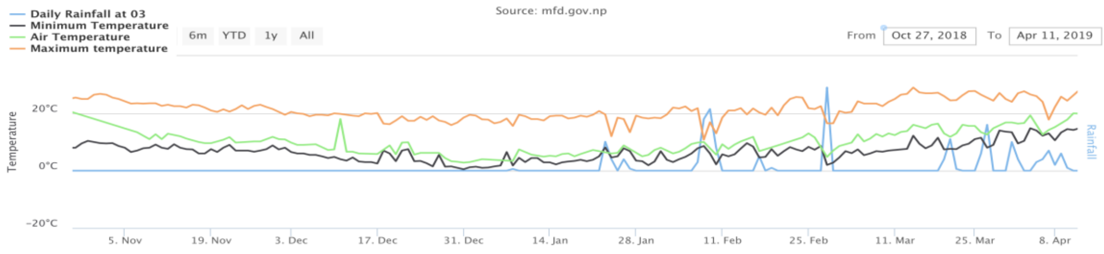


Figure 4. Time duration when ambient temperature is below 20°C [18].

As can be seen in figure 4, the ambient temperature drops below 20°C in the KMC for almost four and a half months. The climate data from the past few years shows a similar pattern for the years 2017-2018, 2016-2017, 2015-2016 and 2014-2015. The average temperature for each day from the beginning of November 2018 until the end of February 2019 can be found in Appendix 1. The period when the maximum temperature fell below 20°C for the winter of 2018-19 can be seen in figure 5.

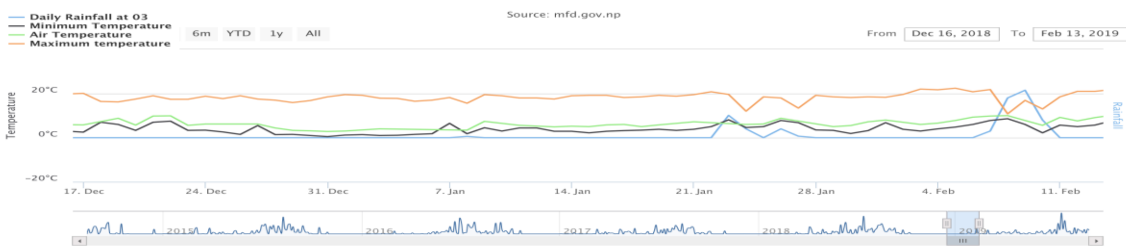


Figure 5. Winter days with maximum temperature below 20°C [18].

During the winter of 2018-2019, the maximum temperature reading starts to slowly slide down below 20°C after December the 16th. Then, it slowly rises back to 20°C and above after February 13th. Thus, the peak winter season can be defined as a period of 50-60 days from mid-December until mid-February.

4.2 Solar Irradiation in Kathmandu

The region between 15° and 35° on the northern and southern hemisphere is often called as the solar belt, the most favourable location for solar applications [19]. Nepal, on and below 30°N, enjoys around 300 days of sunshine a year. On average, the nation receives 3.6-6.2kWh/m^2 of solar irradiation per day. An average insolation intensity of 4.7 kWh/m^2 per day provides a huge potential for harnessing solar energy. [20.]

Solar irradiation data for the KMC are obtained from Nasa's ArcGIS Image Services. The solar radiation data is gathered for the region in green square as shown in figure 6. The region does not represent the KMC in its entirety. However, extending or shrinking the selection region does not change the solar radiation data.

Figure 6. location input for solar radiation data generation [21].

There are several parameters on the solar irradiation database. For the thesis, all sky insolation incident on a horizontal surface is selected for analysis. The data obtained from NASA Langley Research Centre (LaRC) POWER shows an average solar irradiation of 5.24 kWh/m^2 per day. The daily average annual solar irradiation is calculated as an average of the monthly average irradiation per day. [21.] Regmi et al. determined the average sunshine hours for the KMC as 6.5 hours per day per annum. The shortest sunshine hours are in July at 4.0 hours per day and the longest in April and May at 7.8 hours per day. [22.] However, the data gathered from NASA ArcGIS image services suggests 10.43 hours of average daylight in December and 13.87 hours of average daylight in June [21]. Solar irradiation for each day of the winter months 2018 – 2019 can be found in Appendix 2.

Table 1. Average daily solar irradiation, minimum and maximum diffuse radiation for winter months [21].

Month	**Jan**	**Feb**	**Nov**	**Dec**	**Avg.**
Horizontal	4.26	5.15	4.72	4.15	5.24
Diff. $_{\text{Min}}$	0.58	0.81	0.61	0.49	1.35
Diff. $_{\text{Max.}}$	0.95	1.34	0.95	0.90	1.74

Table 1 provides the monthly average solar irradiation measured in kWh/m^2/day along with the minimum and maximum diffuse irradiation also measured in kWh/m^2/day for the winter months. Solar irradiation remains lower during the winter season from November till February and higher between March and October, as shown in table 2 below. The table shows the lowest solar irradiation for December and January. Likewise, diffuse irradiation is found to be lower during the winter and higher during the summer months.

Table 2. Average monthly temperature and solar irradiation in the KMC.

Month	**Average Monthly temperature °C**	**T_{max}**	**T_{min}**	**Average daily Solar irradiation kWh/m^2 /day**	**Average Monthly Irradiation kWh/m2 /month**
January	9.7	17.9	3.8	4.26	132
February	11.9	20.1	6.3	5.15	144
March	16.4	24.9	10.5	6.18	192
April	20.9	29.4	14.5	6.76	203
May	22.8	31	16.7	6.68	207
June	23.5	30.6	18.2	5.75	173
July	22.1	28	18.1	4.79	148
August	21.8	27.8	17.4	4.8	149
September	20.5	27.2	15.4	4.56	137
October	17.4	25.5	11.1	5.13	159
November	13.5	22.5	6.8	4.72	142
December	10.6	19.4	3.8	4.15	129
Yearly	17.6			5.24	1915

Table 2 demonstrates the average monthly temperature and solar irradiation from January till December. It manifests the weather conditions and available solar energy for the KMC over the year. From the table, it can be seen that the solar irradiation from June till September is low. During the monsoon season the cloud cover is higher, with frequent rain resulting in lower solar irradiation. The year-round average temperature is 17.6°C. The average annual solar irradiation is 1,915 kWh/m^2 per year. Monthly maximum and minimum temperatures are also shown in table 2 to portray the temperature variation within the month.

5 Simulated Building

5.1 Building Selection

The KMC building stock is dominated by buildings made with reinforced concrete (RCC). The average household size in the metropolitan is 3.84. [1.] Hence, a multi storeyed residential block with a family of four living in each story is considered in the simulation. The simulated building is a RCC structure with RCC beam and columns, brick walls, cement render, concrete screed, wooden doors, wood and single pane glass windows. The Nepalese National Building code NBC 206:2015, Architectural design requirements for a general residential building, was used as a reference for determining the dimensions of load bearing and non-load bearing structures for the simulation. An urban KMC hosts a diverse range of building designs and layouts. To represent this diversity, a simple basic model of a 10 m x 9 m and five-storey building is designed for a family of four in each story. The model is a representation of a multi-storeyed, resident-owned residential building, prevalent in the dense urban KMC. The floor plan of the building is shown in figure 7 below.

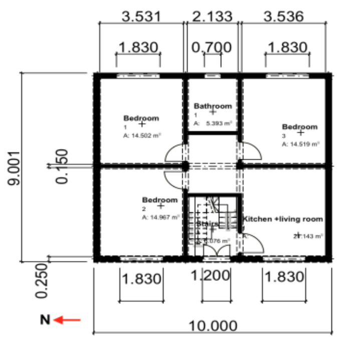


Figure 7. Floor plan of the building.

There are three bedrooms, a bathroom and an open kitchen and living room. The main entrance for the building is on the west wall on the first floor. Access to all floors is via stairs. The floor plan is identical in each flat. The exterior dimensions of the building envelope, dimensions of wall openings, such as doors and windows, along with the wall thickness, is shown in figure 7. The west and south elevations of the building are shown in figure 8.

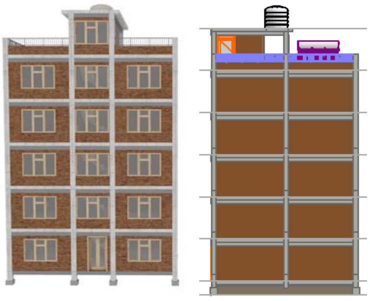


Figure 8. West and south elevation of the building.

Big windows on the eastern and western façade provide natural lighting in the building. The building is a row house built in a dense urban area. The northern and southern facade of the building are attached to the adjacent building. Thus, they are devoid of windows. A typical SWH system installation on the roof can be seen on the southern elevation.

5.2 Solar Water Heating System Specification

An evacuated tube water in glass passive SWH system typical to most of new SWH system installation in KMC is selected for overproduction calculation in the simulated building. The maximum hot water requirements per person is determined at 30-60 litres for a modest residential building [23]. Water at a temperature of 35-40 degrees centigrade is found to be suitable for most domestic uses except for drinking water [4]. Thus, the hot water requirement per each flat for modest use is established at the range of 120-240 litres a day. For the entire building, the requirement of hot water is 600-1200 litres a day. Since the SWH system is installed for a single family use, the hot water requirement is calculated for a single family unit only. The specifications of the SWH system used in the calculation are shown below.

- Tube quantity: 30
- Storage volume: 300 litre
- Storage dimension: 3 m x 0.36 m
- Inner tank diameter: 0.36 m
- Storage tank: 2 mm food grade stainless steel
- Outer tank: 0.4 mm steel

- Tube length: 1899 mm
- Outer tube diameter: 58 mm
- Inner tube diameter: 47mm
- Glass thickness: 1.6 mm
- Thermal expansion: $3.3x10^{-6}$°C
- Absorptivity: 93%
- Insulation: 50mm polyurethane foam [3].

An online platform (T*SOL) is used to determine the optimal inclination angle and orientation. Inclination and orientation of the system are obtained by trial and error method. Data inputs are added for inclination and orientation for maximum output. The SWH system installation is simulated with an optimal angle of inclination at 30 degrees facing south west for maximum hot water production.

6 Quantitative Analysis

6.1 SWH System Output Calculations

SWH system output calculations are performed taking into account the efficiency of the system, absorptivity of the collectors, ambient temperature and heat loss from the storage. All sky insolation incident on a horizontal surface was taken for calculation. The system output is calculated for each day of the winter months, from November until February. Diffuse radiation is not taken into account in the calculation of SWH system's output in order to underestimate the output of the system to compensate for any heat losses of the system through phenomena not included in calculations.

The heating output of the SWH system is calculated as the excess heat available from the SWH after heating the service water to a desirable temperature of 40°C in the study. For the calculation, the solar radiation per square meter, ambient temperature, dimensions of the system, system's absorptivity and losses were known factors. The efficiency of the system can be calculated as

$$\eta = \frac{mc(Tout - Tin)}{AcG} \quad (1)$$

where,

η is the efficiency of the system

mc is the mass and specific capacity of water

Tin is the temperature at the inlet of the solar collector manifold, °C

Tout temperature at the outlet of the solar collector manifold, °C

Ac is the surface area of the collector

G is total irradiance Wm^{-2}.

In order to calculate the efficiency of the SWH system, T_{in} was taken as the temperature measurement at 2 m height and T_{env} was taken as the air temperature. Santosh et al. have determined the solar irradiance for Kathmandu valley, which was used for the efficiency calculation of the SWH system in this thesis. The ratio of $(T_{in} - T_{env})$ /G is calculated and the efficiency of the system was plotted in figure 9. Figure 9, reprinted from J. Arturo et al., represents the efficiency of a water-in-glass evacuated tube, based on an experiment and two other model of efficiency calculation obtained by J. Arturo et al. [23].

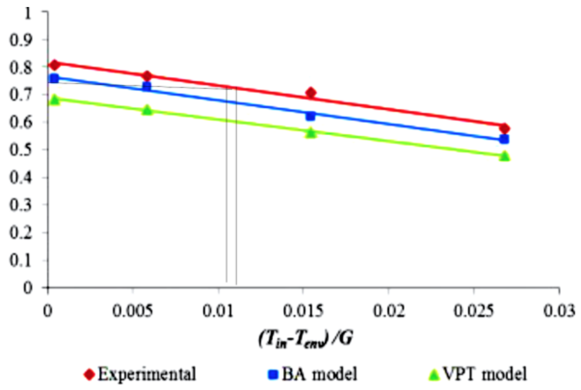


Figure 9. Solar collector efficiency [23].

As the efficiency of the system is determined, the temperature of the hot water in the storage is calculated using the heat equation, Q=ms∆t. Water from the storage is assumed to be drawn in the evening, night and the following morning.

Since the suitable water temperature for domestic hot water is 35°C-40°C, the final temperature for heat release is set at 40°C in the calculation. No heat is to be drawn from the system unless the water temperature exceeds 40°C. The water temperature of the storage tank is calculated for each day using heat equation. In the calculation, the entire tank volume is set to attain identical temperature, determined by the available solar irradiation and ambient temperature. The complex phenomena of temperature stratification, stagnation and mixing are not considered in this study. The temperature of the water in the storage tank is found to have a significant effect on the circulation flow rate of water in the glass tubes. The density gradient of water rises as the temperature rises in the tank with a decline in the viscosity of the water in the storage and hence, further driving the natural circulation of water. [24]. Detailed calculations of heat output can be found in Appendix 3.

Table 3. Excess heat from SWH system's hot water production.

Month	Water volume(l)	DHW temp.	Temp. $_{max}$	Temp. $_{min}$	Heat loss kWh	Efficiency η	Flow l/h	Excess heat kWh
January	300	40	65.4	29.1	17.51	0.75	9.6	149.52
February	300	40	77.5	28.8	14.82	0.73	11.3	194.22
November	300	40	73.4	54.4	14.37	0.75	13.6	247.12
December	300	40	59.7	33.2	17	0.74	8.2	129.24
Total								720.1

Table 3 exhibits the results obtained from the SWH system's output calculations. Energy output for November is almost two folds larger than that of December. December has the lowest energy output, followed by January. However, December and January are the months with the highest heating demand. The average temperature of the water in the storage remained above 53°C for all winter months. The daily water temperature in the storage remained below 40 degrees Celsius for two days in December and January, and for one day in February. The heating required to maintain the water temperature at 40°C during those days was obtained from an electric water heater installed in the storage tank. The heating supplied by electrical heating during such days was deducted from the net available energy for space heating from respective month in the calculation.

Table 4. Available heating power.

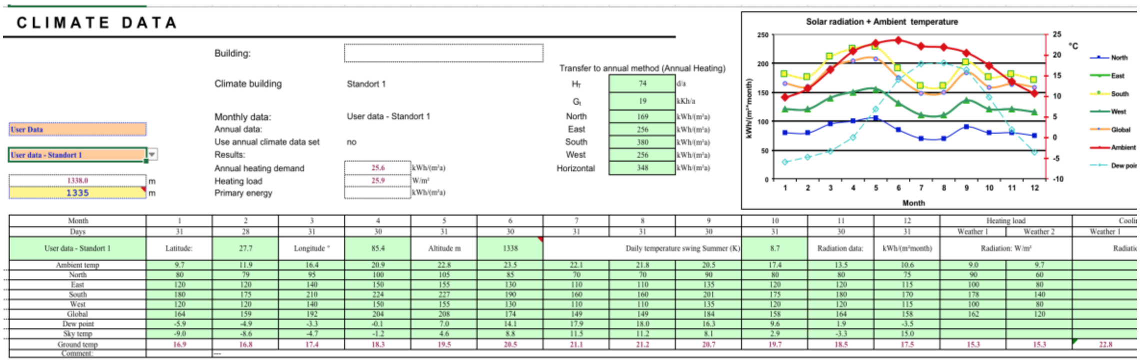
Month	Avg. Sun-light hours	Avg. Heat-ing hours h/d	Available heat kWh	Number of days	Average kWh/d	Avg. Heat-ing Power (W/d)
January	10.6	13.4	149.52	31	4.82	359.94
February	11.25	12.5	194.22	28	6.94	555.2
November	10.82	13.18	247.12	30	8.24	625.19
December	10.43	13.57	129.24	31	4.17	307.22

The average daily heating power output available from a SWH system for the winter months according to the calculation is shown in table 4. The available heat for each winter month can be seen in table 3. The sunlight hours for each day of the month are considered as the same as the average of that month. Heating hours in the simulation are the time from sunset till sunrise. The number is obtained by subtracting the average sunlight hours from the 24 hours of the day. The average heating power output for a day is calculated by dividing the available heat with the number of days in that month and heating hours for the day. The heating power output is given in watts per day. This heating power output is added to the building as space heating in the simulation in chapter 8.2.

6.2 Heating Demand Calculation

Heating demand calculations are computed for the simulated building using PHPP 8.5 version, an excel sheet developed by the Passive House Institute (PHI). PHI is an independent research institute behind the development of an internationally recognised passive house concept, a performance based energy standard in the construction sector. The excel sheet is an easy to use and reliable planning tool for low energy and energy efficient buildings. It can be used to calculate the energy balance of both a new building and a retrofit building. It can be used for various types of construction, building categories and building locations. [25.]

For this thesis, calculations are performed based on a user input weather data. In the absence of climate data for the studied location, climate data were loaded manually from climate data obtained from MFD and NASA Langley Research Centre (LaRC) Power [18; 21]. The input for climate data for heating demand calculations is presented in figure 10.



Month	1	2	3	4	5	6	7	8	9	10	11	12	Heating load		Cooli
Days	31	28	31	30	31	30	31	31	30	31	30	31	Weather 1	Weather 2	Weather 1
User data - Standort 1	Latitude:	27.7	Longitude °	85.4	Altitude m	1338	Daily temperature swing Summer (K)			8.7	Radiation data:	kWh/(m²month)	Radiation: W/m²		Radiatio
Ambient temp	9.7	11.9	16.4	20.9	22.8	23.5	22.1	21.8	20.5	17.4	13.5	10.6	9.0	9.7	
North	80	79	95	100	105	85	70	70	90	80	80	75	90	60	
East	120	120	140	150	155	130	110	110	135	120	120	115	100	80	
South	180	175	210	224	227	190	160	160	201	175	180	170	178	140	
West	120	120	140	150	155	130	110	110	135	120	120	115	100	80	
Global	164	159	192	204	208	174	149	149	184	158	164	158	162	120	
Dew point	-5.9	-4.9	-3.3	-0.1	7.0	14.1	17.9	18.0	16.3	9.6	1.9	-3.5			
Sky temp	-9.0	-8.6	-4.7	-1.2	4.6	8.8	11.5	11.2	8.1	2.9	-3.3	15.0			
Ground temp	16.9	16.8	17.4	18.3	19.5	20.5	21.1	21.2	20.7	19.7	18.5	17.5	15.3	15.3	22.8
Comment:		---													

Figure 10. Climate data input for heating demand calculation [18; 21].

In the thesis, the monthly space heating demand is calculated for the simulated building with indoor winter temperature set at 16°C. Thus, the interior temperature is 4°C lower than that of the passive house standard. The occupancy number in the calculation is 20 in contrast to the 12 based on the passive house standard. The floor to ceiling height in the calculation is 2.4 meters instead of the 2.6 meters of the passive house standard. The location and elevation of the weather station, and the building's altitude above sea level are also listed.

The data input used for area calculations can be found in Appendix 4. Since more than half of the space in the simulated building is occupied by living spaces, the entire floor area is considered as treated floor area. The input used for window sections can be found in Appendix 5. There are twenty-nine windows in the building with twenty-four windows with same dimension and layout. Windows of similar dimension on same façade are listed together. Five small bathroom windows are separately listed for calculation. Adequate shading from adjacent buildings is also taken into account with higher estimation in the calculation to represent dense urban scenarios. Thus, a factor of 0.5 for windows on the west façade and 0.3 for windows on the east façade is listed for the calculation.

Although a ventilation unit was not included in the calculation, the air change rate is taken into account. The air change rate in the calculation is $1h^{-1}$ with the building volume of 950 m^3 and room height 2.4m. Wind protection coefficients are also listed in the calculation.

The thermal quality of the building elements is quantitatively analysed by calculating the U value. The higher the U value is, the more transmission loss there is. Hence, the thermal quality of the element is poor or vice versa. The thermal transmittance or U value for various building elements can be found in table 5. The U values were calculated with dimensions as guided by the national building codes [26; 27]. Since, common building materials are used in the building elements, their thermal conductivities are obtained from the PHPP guidelines [28].

Table 5. U values for all building elements.

Building Element	**Composition**	**Thickness (mm)**	**Thermal conductivity (W/mK)**	**U values (W/m^2K)**
Exterior wall	Brick+2x Render+2x Paint	230+2x13+2x1	0.58, 1.2, 0.22	1.674
Roof	Paint+ Render+ RCC slab+ Screed	1+13+127+64	0.22, 1.4, 2.3, 1.2	3.907
Slab on ground	Stone+ sand+ Brick+ RCC+ Screed	100+100+55+75+5	0.7, 0.25, 0.58, 2.3, 1.4	1.185
Window	Wood + Single pane tinted glass	101+6	0.75	5.8
Door	Wood	60	0.12	2
Floor	Render +RCC slab +Screed+ Paint	13+102+76+1	1.2, 2.3, 1.4, 0.22	3.183
Internal wall	2x Paint+ 2 Render +Brick	2x13+115+2x1	1.2, 0.58, 0.22	2.046
Column	RCC +2xRender +2xPaint	270+2x13+2x1	2.3, 1.2, 0.22	3.143
Beam	RCC +2xRender +2xPaint	230+2x13+2x1	2.3, 1.2, 0.22	3.325

Higher U values for building elements, as seen in table 5, represent poor thermal quality of a building envelope. The materials used in construction are found to have a higher thermal conductivity. In the absence of insulation or insulating technique incorporated in the wall construction, higher heat loss is evident. Similar U values were found by Tri Ratna et al. in their case study [29].

The heating demand is calculated with both an annual method and a monthly method in the PHPP excel sheet. The annual heating method calculates the energy balance using the heating period while the monthly method performs the energy balance for each month of the year. The results obtained are comparable and very similar as the calculations are based on the same climate data. [28.] From the climate data it was established that heating is required from November till February. Hence, the monthly method was used to analyse the heating demand and energy balance.

Detailed heating demand calculations of the simulated building based on monthly data can be found in Appendix 6. The energy balance obtained from the calculation can be seen in figure 11 below. Significant portion of heat is lost from the exterior walls and roof. The heat gain from the windows is much higher than the heat loss from windows. Specific heating contributed for one fourth of the total heat gains. Energy loss from the floor from slab is negative, implying that the ground temperature remained higher than the ambient temperature.

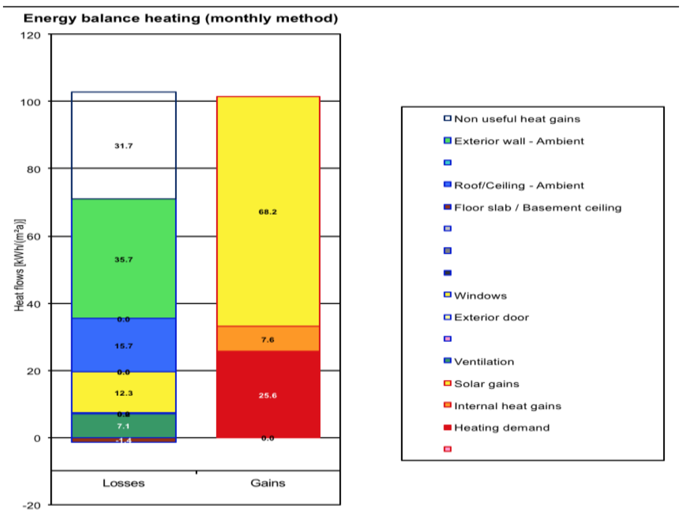


Figure 11. Summary of energy balance.

The space heating demand, obtained from the performed calculations, for each month is presented in figure 12. The total heat gains are represented with yellow while the heating demand is indicated by grey. The maximum heating demand can be seen for January while the heating demand for March is close to zero. 11.7 kWh/m^2 of heating is required in January and 3 kWh/m^2 in November. No heating is required from March till October. Thus, only November-February is considered in further calculations henceforth.

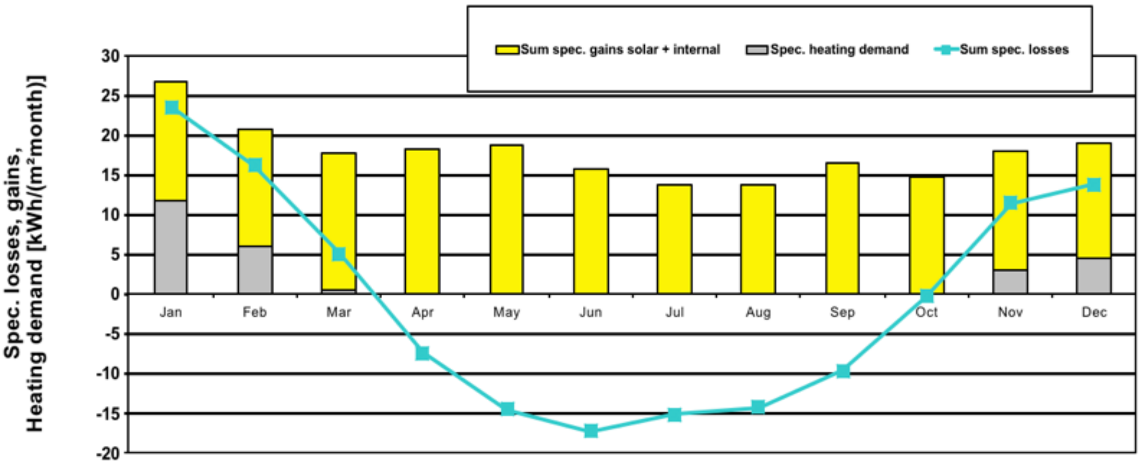


Figure 12. Monthly heating demand from January to December.

Figure 12 reveals the heat gains and heating required for the simulated building in a year. The information in figure 12 is presented in tabular form along with the specific heating demand for the winter months in table 6. The heating demand for the winter months in the study is listed below in table 6.

Table 6. Heating demand for winter months.

Month	Heating demand kWh/m2 month	Heat gain kWh/m2 month	Spec. heating demand kWh/m2 month	Total Spec. heating demand kWh/ month
January	23.6	14.9	11.7	950
February	20.7	14.5	6.1	495
November	17.8	14.8	3	245
December	18.8	14.3	4.5	365

The heating demands of the simulated building for the winter months obtained from the heating demand calculation performed for the sample building are shown above in table 6. The specific heating demand is to be supplied by mechanical heating, which is usually an electric heater in the KMC. The total specific heating demand in kWh for a month is calculated by multiplying the specific heating demand with treated floor area, which is 81 square meters per each flat.

7 Evaluation Parameters

7.1 Thermal Comfort

The Operative temperature in a living space is defined as the combination of average air temperature and mean radiant temperature from surrounding surfaces. It is a common way to measure the indoor thermal comfort as it combines the radiant and conductive heat transfers, providing a better criterion to describe the indoor thermal comfort than air temperature alone. [30.] In this thesis, indoor comfort is defined on the basis of the operating temperature indoors because it describes the change in comfort rather than a mere change in air temperature.

Rijal et al. 2010 found in their study of seasonal and regional thermal comfort in traditional vernacular houses that local residents were satisfied with indoor temperatures that were out of the average range of international thermal comfort standard. Since the difference between the indoor and outdoor temperature remained small, many residents get accustomed to the climate quickly, and felt comfortable. Residents also attributed their adaptation to the climate to a gradual shift in weather from summer to winter or vice versa. Clothing, housing type and the internal heat gains have prominently contributed to the comfort rating of the indoor climate. The daily mean indoor temperature was found to be 11.5°C in the winter in the Bhaktapur district. Rijal et al. also identified the neutral temperature for thermal comfort indoors. For the winter season, 15.2°C was determined as a level when most people felt comfortable. [31.]

Since the climatic condition of Bhaktapur is almost identical to that of the KMC [32], the data for the thermal comfort study from Bhaktapur is taken as standard for the analysis in this thesis. Rijal et al. carried out a research in a traditional building with a higher thermal mass, lower conductivity and more solar penetration. Whereas, the simulated case in the KMC is a building with higher thermal conductivity, lower thermal mass and lower solar penetration. For these reasons, the daily mean indoor temperature in the thesis is set at 11ºC, and the operative temperature at 16°C for indoor thermal comfort. Thus, the operative temperature is to be maintain at and above 16°C for the study.

IDA ICE 4.8 was used for the analysis of the operative temperatures in the building. IDA ICE is a dynamic multi-zone simulation application developed by EQUA, used to study the energy consumption and indoor climate of buildings, tunnels and energy systems. Various climate data, building and energy standards, special systems and languages are available to make simulations precise and accurate. [33.] In the thesis, the building envelope is modelled in the simulation software as shown in figure 13 below.

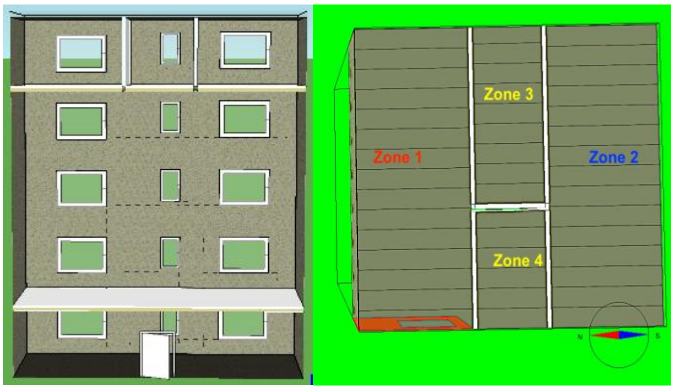


Figure 13. On the left, zone model and on the right, fifth floor zone layout, in IDA ICE.

The first floor is modelled as a single zone, zone 6, and floors 2-4 are modelled as a single unit, zone 5. Since a single family unit is studied, a single flat on the fifth floor is selected in order to reduce the transmission losses of heating. Thus the fifth floor is divided into four zones for a comparative study. Zone 1 comprises two bedrooms along the northern façade, zone 2 is modelled to cover a bedroom, an open kitchen and the living room along the southern façade, zone 3 consists of the bathroom and hallway, and zone 4 is the stairwell.

7.2 Space Heating Demand

In the thesis, the space heating demand is used to analyse the energy saving potential of building envelope modifications, compared to the space heating demand calculated in chapter 6.2. Table 6 is used as a reference value for the analysis. The heating demand of the simulated building is calculated for the building envelope modifications with zero days of operative temperature below 16°C during the simulated period.

The heating demand of simulation models with zero days of below 16°C operative temperature during the simulated period is subtracted from the heating demand obtained in chapter 6.2 to determine the energy saving potential of each such modification. Such difference is shown as kWh/m^2. The energy savings in terms of change in heating demand is calculated by multiplying the change in space heating demand by treated floor area (81m^2). The energy savings are shown as kWh per annum. The energy saving number in kWh is taken as the representation of the magnitude of improvement in thermal envelope.

8 Simulations

8.1 Reference Model, No Heating

In order to quantitatively measure the impact of added space heating, a reference model is required. In the thesis, reference model is simulated with no supplied heating in the building. The reference model is called a base model. For the base model simulation, all heating is disabled, and the climate data for the KMC are included. The U values and other thermal properties of all building elements of the simulated building are aligned with the heating demand calculations. Unlike the thermal properties, internal heat gains are underestimated. For instance, heat gain from home appliances and cooking are abated. Only a heating load simulation is carried out, overheating, cooling load and energy demand are not simulated.

Table 7. Operative temperature of the zones in the base model.

Month	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
November	21.61	22.46	22	22.4	22.86	20.77
December	15.86	16.63	16.19	16.54	17.24	15.63
January	14.77	15.5	15.05	15.44	16.05	14.44
February	19.14	19.8	19.46	19.79	20.02	17.8
Average	17.78	18.53	18.12	18.48	22.86	17.11

Table 7 gives the average operative temperature of the zones in the base model simulation from November to February. The data from table 7 is used as reference data in the analysis. In table 7, it can be seen that the average operative temperature for zone 1 remains the lowest among the zones on the fifth floor. Zone 2 on the fifth floor has the highest average operative temperature. The variation in the operative temperatures of the zones on the fifth floor in the base model is shown in figure 14 below. The lowest operative temperature is found for zone 1, followed by zone 3.

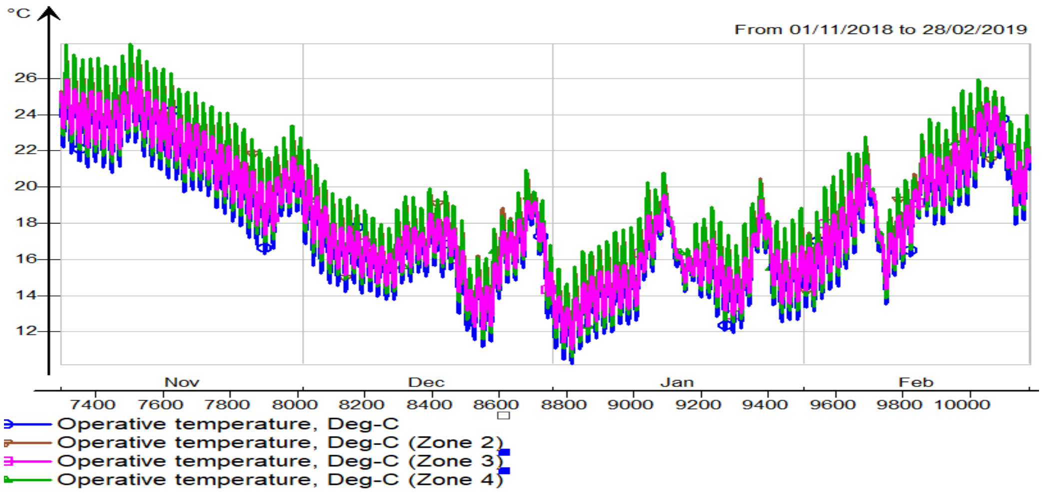


Figure 14. Mean and operative temperature variation throughout winter months.

The operative temperature in the different zones in the simulation of the case building changed from hour to hour of the day. During the mid-afternoon, the operative temperature in the building remained on the higher end as indicated by the colour spectrum in figure 15. The operative temperature slides downwards as the night falls and is at its lowest in the early morning hours. Figure 15 illustrates the variation in operative temperature with time.

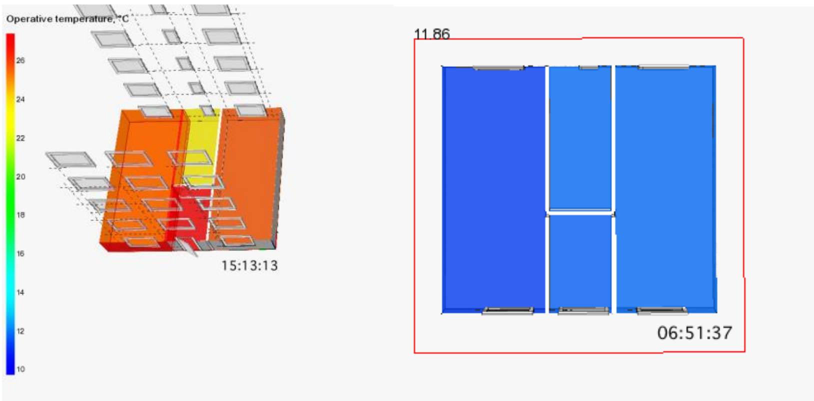


Figure 15. Operating temperature variation with time.

Zones1 and 2 are simulated as inhabited. Therefore, they require a higher thermal comfort. The mean and operative temperatures of zones 1 and 2 are shown in figure 16. The operative temperature remains below the set limit of 16°C for thermal comfort for almost the entire January in both zone 1 and zone 2. However, the operative temperature in zone 1 is much lower than that in zone 2, resulting in a higher level of discomfort in zone 1. The average operative temperature for zone 1 is 17.99°C and for zone 2 is 18.63°C. Likewise, the minimum temperature in zone 1 drops to 14.98°C while for zone 2 it is 15.6°C. Hence, zone 1 is chosen for the simulation of heating and is studied further.

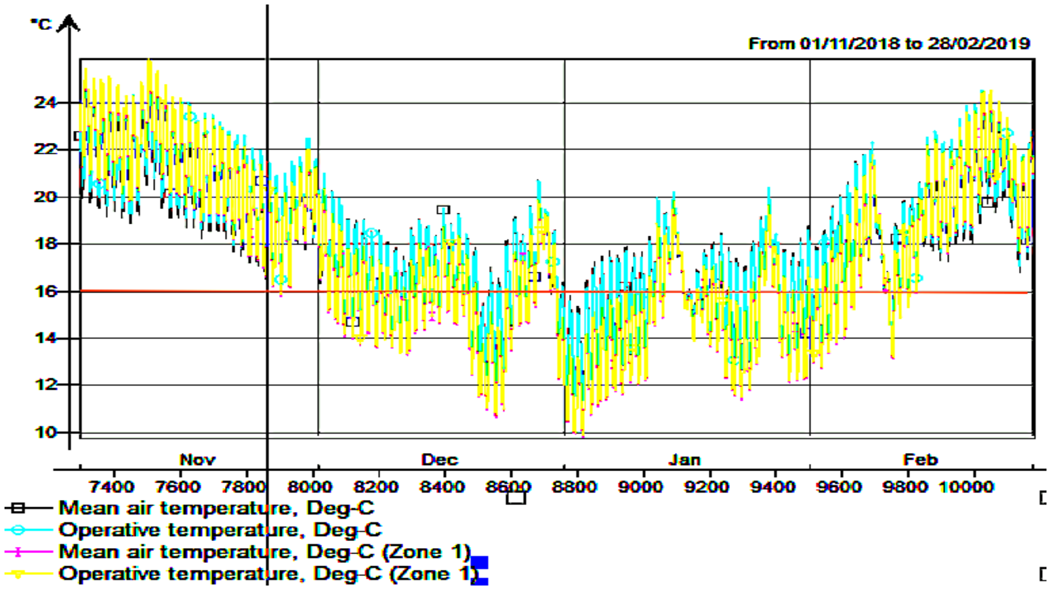


Figure 16. Mean and operative temperature comparison of zone 1 and 2 plotted together.

From the simulation data it can be seen that the temperature within the building envelope drops below the set comfort level for a short time. Nonetheless, the time is significant enough to create discomfort and a need for mechanical heating. Therefore, excess energy obtained from SWH system is introduced to the thermal envelope as space heating in order to improve the thermal comfort of the building and to reduce the energy needed for space heating. The effect of the added space heating in zone 1 and its surrounding zones is discussed in chapter 8.2 below.

8.2 Heat from SWH Overproduction as Space Heating

To analyse the impact of the added heat from the SWH system on the thermal comfort of zone 1, further simulations in IDA ICE are performed. During the second phase of simulation, all the variables are kept identical to the base model simulation. Only a heat source is added with month specific heating power. Heat is supplied to zone 1 and simulations are carried out. The results are discussed and compared with the simulation results for the base model.

Simulations are carried out for November 2018 - February 2019. However, detailed data analysis is performed for December and January only, as the change in operative temperature is noticeable during that period. Moreover, the operating temperature remains above 16°C for November and most of February. Figure 17 shows the full simulation period with the sub division of the simulated period in green.

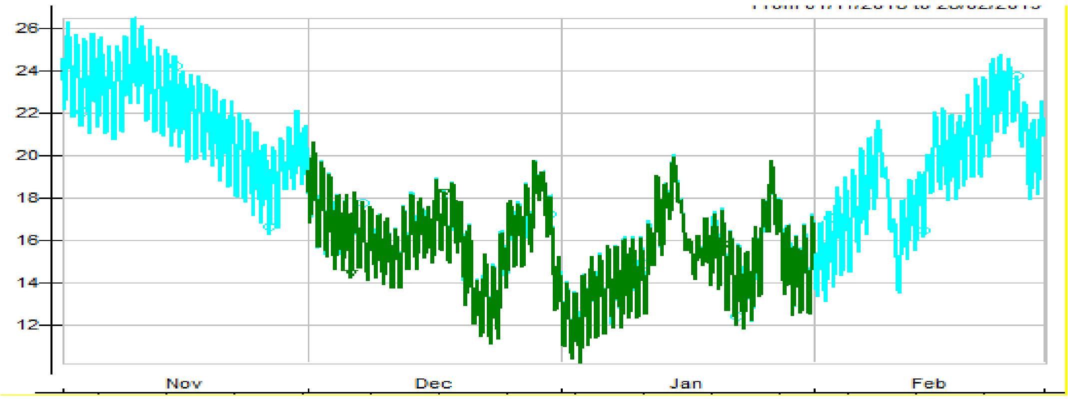


Figure 17. A representation of simulation period division.

December is the month with the least heat output available for space heating, in 2018. With 307 Watts of heating supplied to zone 1 each day. A comparison of the base model simulation and heated zone simulation is shown in figure 18. The comparison shows that the thermal comfort in zone 1 improves slightly for the base model (marked in magenta) to the heated model (marked in blue). Before the introduction of heating, the operative temperature in zone 1 wavered around 16°C for more than 25 days. On the other hand, with heating, the temperature dropped below 16°C for only 13 days. Overall, the operative temperature rose at least a degree.

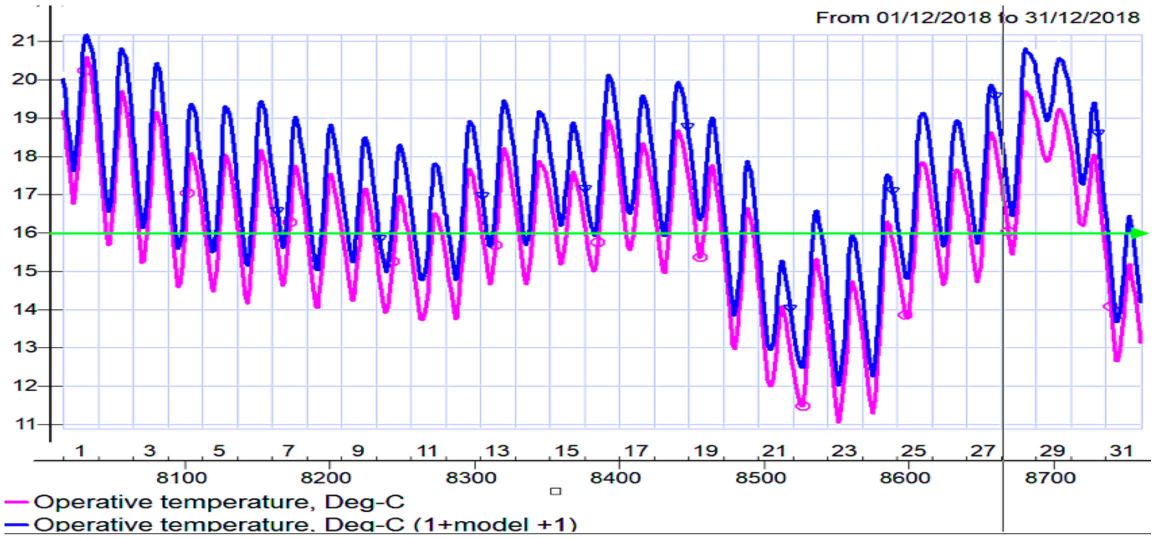


Figure 18. Increase in operative temperature in heated zone 1 against non-heated zone 1 for December.

A similar pattern can be observed in figure 19, representing January. Total of 360 watts of heat is supplied each day to zone 1. Blue indicates the simulation with added heat while magenta represents the base model. After the addition of heat, the operative temperature increases by 1-1.5°C in January.

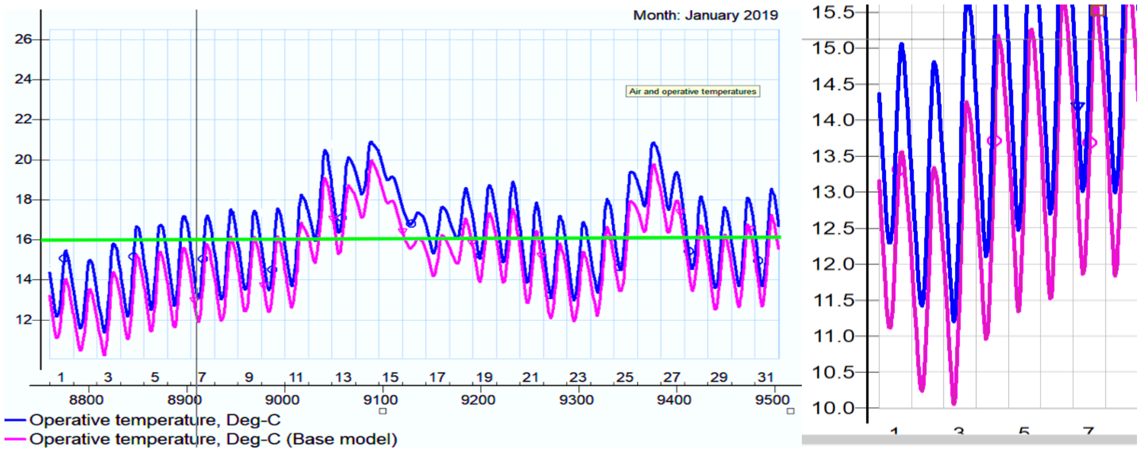


Figure 19. Shift in operative temperature after adding heat to the thermal envelope.

An almost similar temperature pattern is observed till mid-February. After that, the operative temperature starts to quickly ascend above 16°C. Furthermore, the heating output from the SWH system is much higher in February than in December and January. November has the highest heating output with almost 625 watts a day, while the space heating demand is lower in November.

Table 8. Summary of the simulation results for heated and non-heated zone1.

Month	**Base model**				**After heating**			
	Min	**Max**	**Avg.**	**Days<16**	**Min**	**Max**	**Avg.**	**Days<16**
December	12.72	18.53	15.86	13	14.04	19.91	17.21	6
January	11.59	18.53	14.77	25	13.18	19.92	16.24	15

Table 8 provides a summary of the simulation results for the added heating in zone 1 and the base model. Overall, satisfactory improvement in the thermal comfort of zone 1 is found for the coldest month of the year. The operative temperature in zone 1 increased by 1 -1.5 degree Celsius. Moreover, the number of days with an operative temperature below 16°C is reduced by half in December and by more than one-third in January with the added heating. The minimum and average operative temperatures for both months improved by about one degree. The average operative temperature increased by 1.04°C and 1.24°C for December and January, respectively. The introduction of heating to zone 1 also increased the temperatures in the zones around it by a very small margin. The added heating also reduced the gap between the operative temperatures of different zones on the fifth floor. Most importantly, the number of days with an operative temperature below 16°C is reduced from 38 days to 21 days during the studied duration.

Table 9. Operative temperature of each zone before and after heating.

Zones	Avg. Operative temperature							
	November		December		January		February	
	Before	After	Before	After	Before	After	Before	After
Zone 1	21.61	22.1	15.86	17.21	14.77	16.24	19.14	20.41
Zone 2	22.46	22.39	16.63	16.71	15.5	15.59	19.8	19.83
Zone 3	22	22.05	16.19	16.53	15.05	15.45	19.46	20.04
Zone 4	22.4	22.4	16.54	16.84	15.44	15.79	19.79	19.76
Zone 5	22.86	22.77	17.24	17.29	16.05	15.11	20.02	20.02
Zone 6	20.77	20.71	15.63	15.64	14.44	14.46	17.8	17.79

Table 9 lists the obtained operative temperatures from the simulation for each zone before and after the introduction of heating. From the table it can be concurred that a satisfactory improvement in the indoor thermal comfort of the heated zone is accomplished. The average operative temperature for zone 1 in January has risen above 16°C with a minimum of 13.18°C. Hence, the potential of providing space heating from excess energy of an oversized SWH system is realised with a satisfactory improvement in the thermal comfort of the heated zone.

Despite the improvement of the thermal comfort in the heated zone, the operative temperature in the heated zone of the simulated building is found to be below the set limit of thermal comfort for twenty-one days during the simulated period. Likewise, the change in the operative temperature and improvement in thermal comfort in non-heated zones is negligible over the monthly data. Therefore, thesis deemed that the excess heat available from a SWH system is insufficient to maintain the thermal comfort at the set level throughout the studied period. Therefore, an alternative approach of building envelope modification is studied.

9 Building Envelope Modifications

It was seen in chapter 8.2 above that the space heating supplied from the overproduction of SWH system is inadequate to maintain the operative temperature at the set level of thermal comfort. Therefore, alternative proposals are made to insulate different building elements. The insulation that is used in the modification simulations is a 50 mm rigid polystyrene foam. As the simulation only provided space heating to a specific zone on the fifth floor, all the modifications are also defined for the fifth floor only. The specified heating output for each month from table 4 is used unless mentioned otherwise in an alternative proposal. The parameters for simulation are identical to those in the heated model simulation in chapter 8.2 unless mentioned otherwise. In order to maintain the operative temperature at and above 16°C, the following alternatives are considered and simulated to analyse their performance:

1. Insulated floor
2. Insulation of External walls
3. Insulation of Roof on zone 1
4. Insulated roof
5. Insulated roof, floor and interior walls
6. Insulation of roof and north wall of zone 1
7. Insulation in external walls and roof of zone 1
8. Insulation in north wall of zone 1 and entire roof
9. Insulation of all exterior walls and roof

9.1 Insulated Floor

A 50 mm insulation is added to the floor on the fifth floor and a simulation is carried out with identical parameters as those in the heated model simulation. The results are also identical to those of the simulations from the heated model. No visible change is documented for the simulated period. The average operative temperature remains at 16.24°C for January and 17.21°C for December. Furthermore, fifteen days in January and six days in December have operative temperatures below 16°C.

Since the impact of added insulation does not affect the outcome of the simulation, the effect of insulation on the floor is deemed negligible. Hence, the modification is considered an unsuitable option, and further alternatives are modelled and simulated.

9.2 Insulation of External Walls

Simulations are performed with a 50 mm insulation on all external walls on the fifth floor and the heating specified in the simulation in chapter 8.2 for the simulated month. Although, the operative temperature increases slightly due to the insulation, there are still sixteen (12+4) days during the simulated period when the temperature drops below 16°C. The results obtained for December can be found in figure 20. The simulation with insulated external walls is represented in green, followed by the simulation with heating only in blue and the base model simulation in magenta.

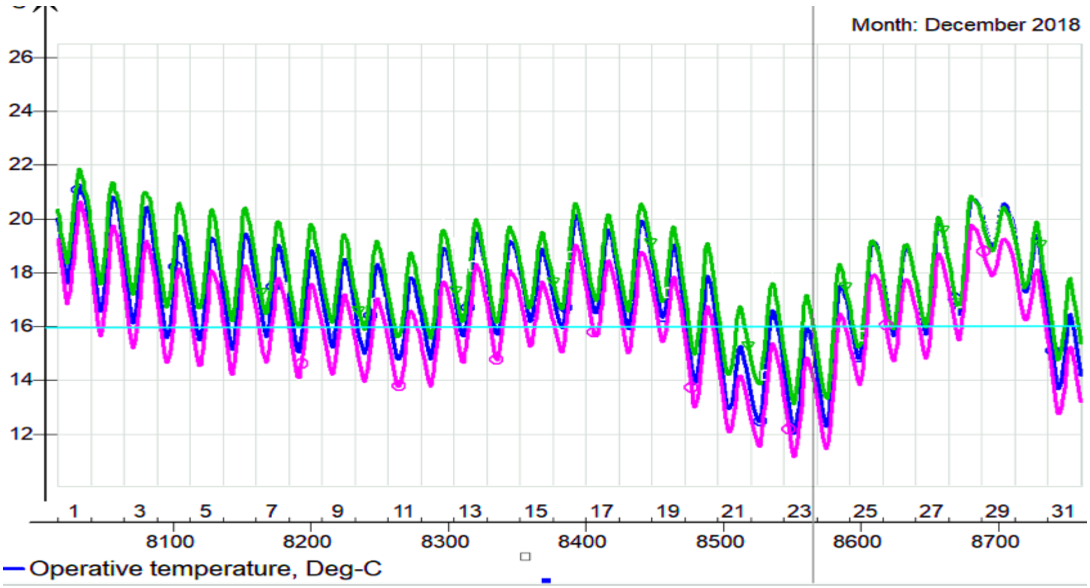


Figure 20. Operative temperature with insulated exterior wall compared with base models

From figure 20 it is clear that the operative temperature in the simulation has risen above the set temperature of 16°C. Similar observations are also made for January. The average operative temperature is 16.69°C with a minimum of 13.98°C in January. Likewise, the average operative temperature is 17.6°C with a minimum of 14.66°C in December. Adding insulation on the external walls improves the indoor thermal comfort, but cannot maintain the operative temperature throughout the period. The temperature oscillated in unison with the temperature of the heated simulation with a dismal increase. Hence, other alterations are proposed and studied in the following chapters.

9.3 Insulation of Roof on Zone 1

To improve thermal performance of the building, the next simulation is run with added insulation to the roof in zone 1. The results of the simulation are satisfactory, six days in January and three days in December have an operative temperature below 16ºC. The average operative temperature is 17.24°C for January and 18.2°C for December. The added insulation in the roof of zone 1 reduced the number of days with operative temperatures below 16°C by half in December and January compared to the simulation in chapter 8.2.

Though the added roof insulation in zone 1 performs excellently, the modification cannot maintain the operative temperature throughout the winter at 16°C. Therefore, further modifications, discussed below, are needed.

9.4 Insulated Roof

In the sixth simulation, insulation is added to the entire roof and the simulation is carried out with the heating option being the same as described in chapter 8.2. The building envelope performs efficiently after the modification. The change in the operative temperature for December can be seen in figure 21 marked in green.

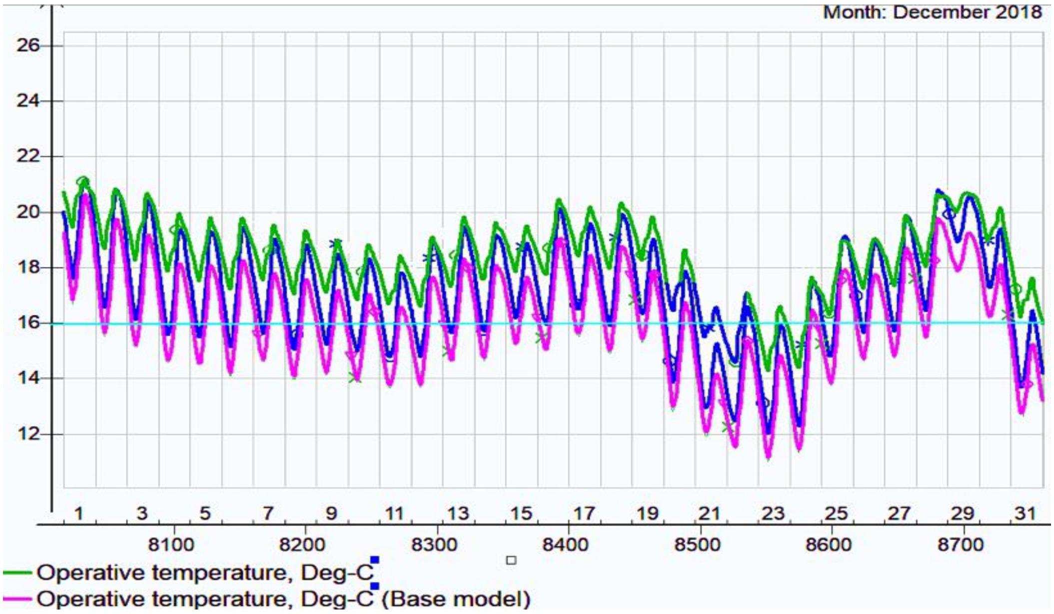


Figure 21. Operative temperatures with insulated roof compared to base models

The average operative temperature in the simulation with the insulated roof is 17.45°C and 18.42°C for January and December, respectively. Four days in January and one day in December have an operative temperature below 16°C. Moreover, the added insulation reduces the heating demand for the winter months. The specific heating demand for January fell from 11.7 kWh/m^2 to 9.5 kWh/m^2. Likewise, the specific heating demand for December is reduced by more than a half to 2.1 kWh/m^2. Overall, a reduction of nearly 400 kWh of heating annually is achieved with the installation of insulation on entire roof. However, the results indicate that the roof insulation alone is not enough to maintain good thermal comfort in zone 1 throughout the winter. Therefore, further modifications and simulations are carried out.

9.5 Insulated Roof, Floor and Interior Walls

The next simulation is modified by adding insulation to the floor, interior walls and the entire roof on the fifth floor. The results of the simulation do not show any noticeable and verifiable change compared to results obtained with only insulated roof, discussed in the previous chapter. The effect of added insulation on the internal walls and the floor is therefore insignificant.

As discussed in chapter 9.1, the effect of added insulation on the floor is inconsequential. The same is true for added insulation on the internal walls. Thus, the modification with roof, floor and internal walls insulation is deemed futile.

9.6 Insulation of Roof and Northern Wall of Zone 1

For the following simulation, the wall on the northern facade and the roof in zone 1 are insulated. The specific heat output of the simulated month is added to Zone1. All other parameters are identical to those of the heated model in chapter 8.2. The results of the simulation of this alteration gives better results than the previously discussed adjustments. The average operative temperature is 17.91°C for January and 18.79°C for December. Only two days in January fell below the set operative temperature limit of 16°C. Detailed operative temperatures for the month of January can be found in Appendix 7. When 50 m^2 of insulation is added on the north wall and roof of the heated zone, the heating demand decreases by 2.5 kWh/m^2 to 22.8 kWh/m^2 annually, saving 200 kWh of heating energy each year.

Overall, the results obtained from this adjustment are substantial, and this may be the best alternative in when comparing to the added cost of insulation to the added energy savings for existing buildings in the KMC. However, an alternative solution that can provide a stable thermal comfort throughout the winter is still desirable. Therefore, more simulations are run.

9.7 Insulation in External Walls and Roof of Zone 1

In this simulation, only the external walls and the roof of the heated space, zone 1, are insulated. The simulations are carried out with identical parameters to those of the heated mode in chapter 8.2. The simulation results suggest that this alternative maintains the operative temperature throughout the simulated period at set level of 16°C successfully. The average operative temperature in January is 18.21°C and in December 19.06°C. According to the simulation, the minimum operative temperature for January is

16.19°C and for December 16.72°C. The operative temperature for each day of January for all the zones can be found in Appendix 8.

Adding 60 m^2 of insulation on the exterior walls and the roof on zone 1 decreases the heating demand by 3.1 kWh/m^2, to 22.2 kWh/m^2 annually. Annually, 250 kWh of heating energy savings are obtained for the household on the fifth floor in the simulation.

The alternative with the insulated external walls and roof maintains the operative temperature at a set level of thermal comfort successfully for the studied duration. However, in order to determine the optimal modification and to study the change in thermal comfort in adjacent zones, some other alternatives are also studied.

9.8 Insulation in North Wall of Zone 1 and Entire Roof

A simulation conducted with an insulated roof and north wall on the fifth floor produces a significant improvement in the operative temperature of zone 1. According to the simulation, the operative temperature stays above 16°C in both January and December. The average operative temperature for January is 18.15°C, with a minimum of 16.11°C and for December 19.04°C with a minimum of 16.72°C. The modification successfully maintains the operative temperature at and above 16°C throughout the simulated period. Simulated operative temperature for each zone for January can be found in Appendix 9.

The addition of 100 m^2 of insulation on the northern wall on the fifth floor and on the entire roof also decreases the building's specific heating demand. The specific heating demand is reduced by a quarter with this alteration in the building envelope. The space heating demand for each month after the alteration is shown in figure 22 below.

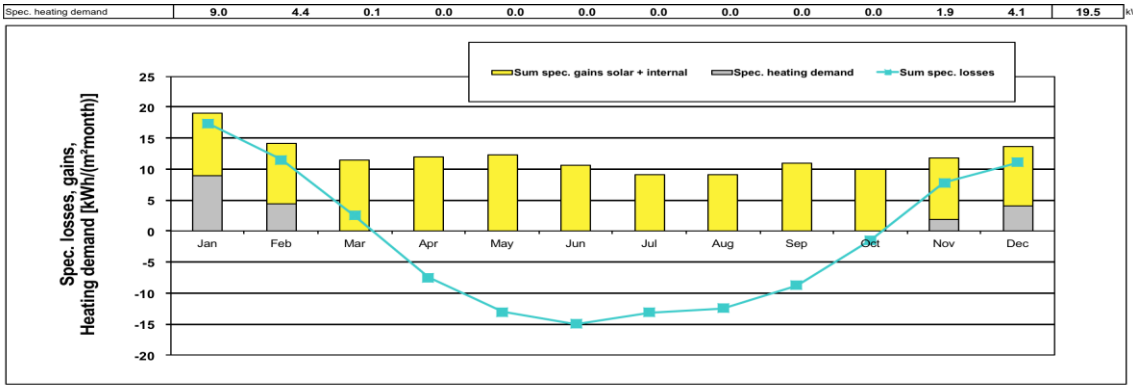


Figure 22. specific heating demand for building envelope alteration in chapter 9.8

The performance of the simulation model with the insulation added to the northern wall of zone 1 and the entire roof is analysed with the operative temperature and specific heating demand. The modification with insulation on north wall of zone 1 and on the entire roof improves the indoor thermal comfort while reducing the monthly specific heating demand. The operative temperature increases by almost two degrees and the heating demand reduces by 5.8 kWh/m^2 annually. The saving is almost 470 kWh of heating energy annually for the residents of the fifth floor of the simulated building.

From the obtained simulation results it can be concurred that the proposal of adding 50 mm insulation on the entire roof and northern wall on the fifth floor is sufficient to maintain the operative temperature at the set level of 16°C throughout the winter. The alteration discussed in chapter 9.8 produces a uniform operative temperature in and around the heated zone on the fifth floor. The average operative temperature for all zones on the fifth floor is above the set limit. However, to substantiate the findings of chapter 9.8 as an optimal modification, one further alteration is studied.

9.9 Insulation of All Exterior Walls and Roof

In final simulation, all the exterior walls and the roof on the fifth floor are insulated. With the insulated walls and roof, the quality of the thermal envelope improves. With the improved thermal envelope, a simulation is carried out with all other parameters identical with the heated model simulated in chapter 8.2.

Table 10. Improved U values for insulated building elements.

Building Element	Composition	Thickness (mm)	Thermal conductivity (W/m K)	U values (W/m^2K)		Insulated area m^2
				Before	After	
Exterior wall	Brick+2x Render+2x Paint+ Insulation	230+2x13+2x 1+50	0.58, 1.2, 0.22, 0.035	1.674	0.494	74
Roof	Paint+ Render+ RCC slab+ Screed + Insulation	1+13+127+64 +50	0.22, 1.4, 2.3, 1.2, 0.035	3.907	0.594	81

Table 10 shows the changes in U values with the addition of insulation to the whole exterior walls and the roof. As shown in table 10, the thermal property of the walls and the roof is improved significantly. This should improve the thermal comfort in same proportion. Adding insulation to the exterior walls and the roof reduces the thermal loss significantly.

The results obtained from the final simulation show a significant change in the operative temperature. The average operative temperature for January in this simulation is 18.54°C, with a minimum operative temperature of 16.79°C, implying that the operative temperature remains above 16°C throughout the month. Similar results are obtained for December where the average operative temperature was of 19.38°C and a minimum operative temperature of 17.33°C are registered. The operative temperatures for the arrangement in the final simulation is indicated with green line in figure 23. The blue line represents the heated model simulated in chapter 8.2.

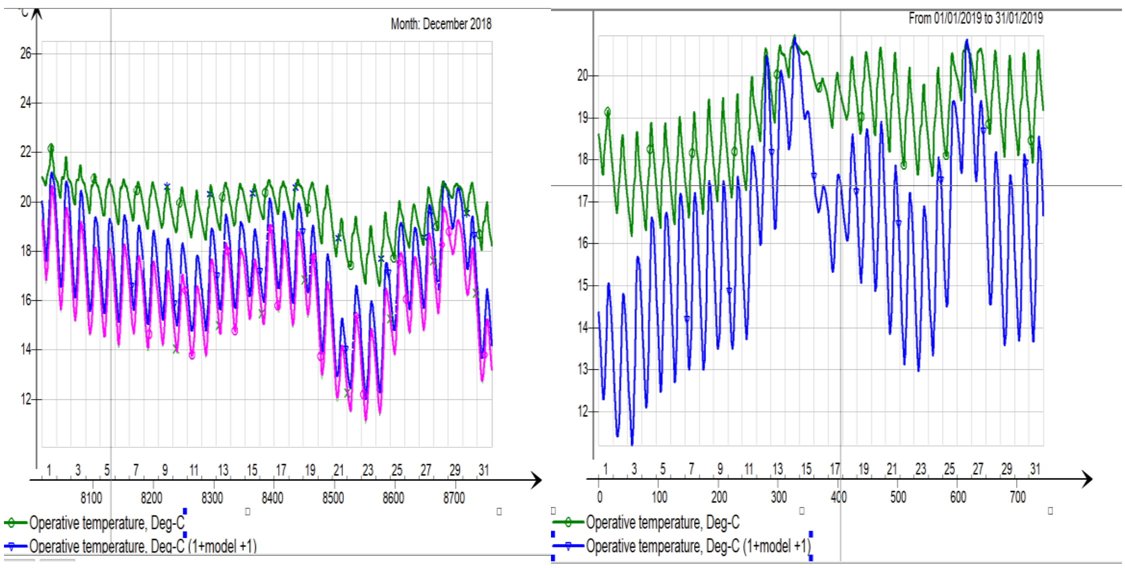


Figure 23. Operative temperatures for December and January with all exterior walls and roof insulated

The operative temperature remains above 16°C in the heated zone for the entire simulation period. If the supplied heat were to be withdrawn, the operative temperature would fall below the 16°C limit for 2-5 days in the winter. Hence, the combination of insulated exterior walls and roof with the excess heat from the SWH system as heating can reduce the need for any other form of mechanical heating during cold winter days. The operative temperature for December and January in this simulation can be found in Appendix 10.

Table 11. Operative temperatures results.

<table>
<tr><th colspan="2">Month</th><th>Zone 1</th><th>Zone 2</th><th>Zone 3</th><th>Zone 4</th><th>Zone 5</th><th>Zone 6</th></tr>
<tr><td colspan="2">January</td><td>18.54</td><td>16.73</td><td>17.11</td><td>17.25</td><td>15.91</td><td>15.05</td></tr>
<tr><td colspan="2">December</td><td>19.38</td><td>18.01</td><td>18.28</td><td>18.39</td><td>17.09</td><td>16.23</td></tr>
<tr><td colspan="2">T<16 Jan. days</td><td>0</td><td>9</td><td>7</td><td>6</td><td></td><td></td></tr>
<tr><td colspan="2">T<16 Dec. days</td><td>0</td><td>2</td><td>0</td><td>0</td><td></td><td></td></tr>
<tr><td rowspan="4">No Heat</td><td>January</td><td>16.21</td><td rowspan="2">16.52</td><td rowspan="2">16.39</td><td rowspan="2">16.63</td><td rowspan="2">15.72</td><td rowspan="2">14.97</td></tr>
<tr><td>T<16</td><td>11</td></tr>
<tr><td>December</td><td>17.57</td><td rowspan="2">17.89</td><td rowspan="2">17.78</td><td rowspan="2">17.96</td><td rowspan="2">16.97</td><td rowspan="2">16.2</td></tr>
<tr><td>T<16</td><td>3</td></tr>
</table>

Table 11 provides a summary of the results obtained from the simulation in chapter 9.9. The average operative temperature for January and December remains above 16°C on the fifth floor. However, for nine days in January and two days in December the temperature in zone 2 stayed below the16°C limit. In zones 3 and 4, the temperature fell below 16°C for seven and six days, respectively, in January. In zones 5 and 6 the operative temperature stayed below 16°C for almost the whole of January. Table 11 also documents the operative temperature for all zones when heating was withdrawn from the system. When heating was removed, the operative temperature in all zones fell, and the days with an operative temperature below the set limit of 16°C increased by 14 days in zone 1, concluding the importance of the supplied heat for maintaining indoor thermal comfort.

In chapter 9.9, 155 m^2 of insulation is added to the building envelope. Adding insulation on the whole external wall and the roof on the fifth floor also reduces the space heating demand from 25.3 kWh/m^2 to 17.5 kWh/m^2. The final arrangement saves 7.8 kWh/m^2 in space heating, amounting to 630 kWh of energy annually. The modification in chapter 9.9 attains the highest energy savings and highest average operative temperature on the fifth floor of the simulated building among the simulated modification models.

10 Determination of Optimal Modification

In order to determine the optimal modification, the modification models are analysed and compared based on the operative temperatures and the energy savings. From the alternative modifications, insulation of roof and northern wall of zone 1 (9.6), insulation in exterior walls and roof of zone 1 (9.7), insulation in north wall of zone 1 and entire roof (9.8) and insulation of all exterior walls and roof (9.9) produce a desirable outcome. Hence these alternatives are compared on the basis of average operative temperature in and around the heated zone, area of added insulation, and energy savings potential.

Table 12. Comparison of desirable modification models based on defined parameters.

Insulated area	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Insu-lated area(m^2)**	**Energy kWh/ yr.**
Insulation of roof and northern wall of zone 1	17.91	15.68	15.84	16.06	15.72	14.97	50	220
Insulation in exterior walls and roof of zone 1	18.21	15.7	15.91	16.13	15.75	14.98	60	250
Insulation in north wall of zone 1 and entire roof	18.15	16.59	16.8	16.56	15.85	15.03	100	470
Insulation of exterior walls and roof	18.54	16.73	17.11	17.25	15.91	15.05	155	630

Table 12 summarises the findings of chapters 9.6 - 9.9. From the table, it can be concluded that the alternative with insulation in north wall of zone 1 and entire roof produced the highest energy savings ratio of 4.7 to insulated area. Moreover, the modification also maintains the average operative temperature of above 16°C on the entire fifth floor. Likewise, it also maintains a uniform temperature across the fifth floor. Furthermore, the temperature difference of the heated zone and the coldest zone is lowest at 1.59°C, thus potentially minimising cold draughts.

Based upon these findings it can be concluded that the alternative with insulation in north wall of zone 1 and entire roof is an optimal alteration combined with heating provided by excess energy from SWH system overproduction. Any improvement in the thermal comfort in zone 1 is reflected to the surrounding zones as well and a uniform temperature on all zones are obtained. Thus, the alternative in chapter 9.8, insulation in north wall of zone 1 and entire roof is the most desirable alternative for a typical household in the KMC.

11 Results

The calculation of the overproduction of the studied SWH system established that least energy is available for December and January when the heating demand is at its highest. Nonetheless, 307 and 360 watts of heating power was available for each day of the respective month. The heating was dispensed over a period of thirteen hours each day. A daily average of 4.2 kWh and 4.8 kWh of heating was available in December and January, respectively.

The heating demand calculations exhibit the necessity of an additional heating of 25.3 kWh/m^2 annually. The poor thermal quality of the building elements was determined from the U value calculations. The transmission losses from the building envelope was also found to be high. Only four months in a year required heating. Most heating was required for January and February. Most of the heat losses occurred through the external walls and roof.

Simulations performed on the base model illustrate the temperature variation within each zone of the simulated building at different hours of the day. The minimum temperatures were recorded during the early hours before sunrise. The highest temperatures were observed during the mid-afternoon. The mean temperatures indoors were found to be in the same range as assumed on the basis of literature, that is, 11°C. On the fifth floor, the lowest average operative temperature was found in zone 1 on the northern façade. When the entire building was considered, the lowest operative temperature was seen on the first floor.

With the added heat from the excess energy from the SWH system, the operative temperature in zone 1 increased by 1-1.5°C. In addition, the operative temperature of the surrounding zones rose. Most importantly, the number of days when the operative temperature in the simulated heated zone was less than 16°C were reduced by half in December and by more than one-third in January. Overall, the heating supplied from the SWH system improved the thermal comfort in the heated space. Although, the result obtained was satisfactory, the operative temperature was not kept at the set level of 16°C for twenty-one days during the simulated period.

The modification simulations showed that the effect of insulation added in the floors and internal walls on the thermal comfort was insignificant. Adding insulation on the entire roof had a better effect than insulating all the exterior walls on the fifth floor. Days with an operative temperature below 16°C were fewer with an insulated roof than with insulated exterior walls. Furthermore, the temperature variations were smaller with an insulated roof than with insulated external walls.

When insulation was added on the north wall and the roof of zone 1, the simulation gave as a result good thermal comfort in zone 1. Only two days of the entire simulated period had a temperature below the set limit of 16°C. The modification is suitable to heat a specific zone in the KMC in order to ensure satisfactory thermal comfort with minimal insulation.

The thermal comfort was maintained above the set limit of 16°C by three of the simulated alternatives: insulation in exterior walls and roof of zone 1 (9.7), insulation in north wall of zone 1 and entire roof (9.8) and insulation of all exterior walls and roof (9.9). Among these three models, the one with insulation in north wall of zone 1 and entire roof (9.8) outperformed the other two models. It was able to maintain the average operative temperature above 16.5°C not only in zone 1 but also in all adjacent zones on the fifth floor. On the other hand, insulation in exterior walls and roof of zone 1 (9.7) was only sufficient to maintain the operative temperature in the heated space. The average operative temperature in the adjacent zones was below 16°C. When all exterior walls and the whole roof was insulated (9.9), the result was a highly desirable thermal comfort indoors, with an average operative temperature above 16.7°C in all zones on the fifth floor throughout the simulated time. However, as the project requirement was a minimal insulated area and the highest ratio of energy savings to added insulation, the alternative where insulation was added on the whole roof and north wall of zone 1 (9.8) produced a better thermal comfort output than the other two models.

From the study it is established that an oversized SWH system offers a potential for the utilisation of overproduction into space heating during the winter in the KMC. The added heating produced a desirable change in the indoor thermal comfort of the heated space validating the hypothesis of this study. However, the energy of overproduction alone was shown to be insufficient to maintain the thermal comfort at a desirable level throughout the winter. Nevertheless, when combined with a suitable building envelope alteration, it was able to maintain the thermal comfort at a desirable level in the heated space. With the proper alteration, it was also able to maintain the thermal comfort at a desirable level in all the adjacent zones on the fifth floor of the simulated building. Of the nine alternatives simulated, four arrangements met the desired requirements. They are listed below with the one using least insulation first.

1. Insulation of roof and northern wall of zone 1 (50 m^2)
2. Insulation in exterior walls and roof of zone 1 (60 m^2)
3. Insulation in north wall of zone 1 and entire roof (100 m^2)
4. Insulation of all exterior wall and roof (155 m^2).

The alternatives with the least insulation added to the building, insulation of roof and northern wall of zone 1 (9.6) and insulation in exterior walls and roof of zone 1 (9.7) produced a satisfactory result. The combination is an optimal solution if only a small single space is to be heated with minimal insulation. Since it is desirable to have a good thermal comfort in all living spaces, only alternatives in chapter 9.8, insulation in north wall of zone 1 and entire roof and chapter 9.8, insulation of all exterior wall and roof, delivered an enticing result. The modification on chapter 9.8, insulation in north wall of zone 1 and entire roof (3) was found to be the optimal modification. The model could maintain a desirable thermal comfort in the heated space and also improve the thermal comfort in the surrounding zones with less insulation added. Furthermore, the temperature difference between the heated and non-heated space was lower than with insulation of all exterior wall and roof in chapter 9.9.

12 Discussion

The results obtained in the thesis validate the potential of the use of excess energy from the overproduction from an oversized SWH system. This free energy can be used to heat spaces during the winter. However, the space heating obtained is not alone enough to heat the space to a comfortable temperature. Although additional heating is required to maintain a warm indoor temperature, the number of heating hours is minimised with the added heat. In this thesis, heating is supplied over the entire length of heating hours and over a large area (33.8 m^2). The heating can be designed to supply heat over a shorter period to effectively provide sufficient heating for small spaces. Furthermore, the heating method might affect the performance of the system, the performance of an underfloor heating system in low temperature is higher than that of wall mounted radiators.

In this thesis, a number of assumptions were made. Some complex losses of the SWH system were not considered. At the same time, internal gains were underestimated, and diffuse radiation was neglected. With this conservative approach in calculations, the findings of this study can be taken as the minimum guaranteed potential of the system. Furthermore, the simulations were performed a number of times to validate the outcome.

The simulated building is a row house, attached to another building on its northern and southern facades. This was not taken into account when studying the thermal comfort in the thesis. If the adjacent buildings are considered in the simulation, the thermal comfort of the building improves by 0.5°C. Likewise, the north and south facades were kept exposed to the ambient air in the heating demand calculation to overestimate the heat losses. If the north and south facades were calculated as exposed to indoor temperature, the heating demand of the building was found to reduce by 1 kWh/m^2 annually. The effect of shadings was also considered sufficiently in the heating demand calculation.

The possibility of enlarging the collector area during the winter is vital in increasing the heat output. The increased output can bring a substantial increment in the thermal comfort indoors during the winter. If a large system is installed primarily for space heating during the winter, it is recommended to consider the potential to downsize the system for the summer. Challenges of excess overproduction are not discussed in the study. Only excess production during winter is studied. In the summer, when the demand is much lower, the overproduction is much higher. Hence, the challenges of overproduction should not be neglected.

No economic or technical analysis was carried out to measure the feasibility and applicability of the proposal. This thesis aimed to explore and analyse the mere potential of the system. Furthermore, potential modification on the existing structure were studied. The modifications combined with the added heat were studied to analyse the suitability of a SWH system’s excess energy to maintain the thermal comfort at a set level during the winter.

Before integrating the excess production of a SWH system to space heating, it is recommended to ensure the existence of overproduction in the SWH system. An undersized system is not sufficient to provide any space heating. The hot water demand has to be considered before deciding the overproduction. A SWH system's output usage priority has to be set. In the study the priority was to provide domestic hot water.

The findings of the thesis can be taken as a reference for experimentation of space heating systems. The thesis explores space heating potential from the excess energy of an oversized SWH system. Space heating experiments can be carried out in order to verify the findings of the study. An experimental verification of this study can explore a new potential for space heating in the KMC. The findings can be equally beneficial for new and existing buildings if space heating is to be integrated in the building.

The outcome of this thesis can be further studied together with other systems for space heating. For example, water heating from photovoltaic systems can increase the energy output of the system for heating. Likewise, the overproduction could be integrated with heat pump systems. A number of studies have been done for a SWH system combined with a heat pump in various regions of China. Furthermore, the available heating output could be studied in a comparative study of floor heating and wall heating.

13 Conclusion

The potential of supplying space heating from the overproduction of a SWH system has been analysed and found to deliver a satisfactory improvement in the thermal comfort of the heated zone. The rational is guaranteed to improve the thermal comfort of the space over the entire heating period. However, the heating supplied only this way was not able to maintain the thermal comfort of the heated space throughout the studied period, implying that the proposed rational is not a viable source of heat supply in the conventional term.

However, when the heating was supplied with a strategic insulation of the building envelope, it was possible to maintain the thermal comfort of the heated space throughout the winter. Moreover, proper insulation of the building envelope could also improve the thermal comfort of the non-heated zones adjacent to the heated zone. Simulations performed in the study demonstrated that the necessity for mechanical heating can be minimized by improving the thermal envelope of the building.

The results obtained in the study provide a reference for the expected change in the thermal comfort in buildings in the KMC when using such heating application as an oversized SWH system. The overproduction of the SWH system can be used in the existing buildings of the KMC to improve the thermal comfort of the heated zones and to reduce the number of heating days in the winter. This thesis could also be used to design a heating system to provide periodic or scheduled heating in small spaces.

To provide a reliable heating source, the findings of the thesis can be studied in combination with other heating sources. Furthermore, different heating systems for heat supply could be investigated further to identify a suitable heating method for the area. Internal heat gains could be considered adequately, and an actual reduction in the space heating demand could be investigated by experimentation.

Therefore, it can be concluded that the excess heat from SWH systems is not sufficient enough to heat an entire apartment. However, it is sufficient enough to heat a specific space in order to maintain a good thermal comfort when minimal insulation is added. Moreover, when insulation and heating are added strategically, the excess energy of a SWH system is found to be sufficient to maintain the thermal comfort of an apartment for most of the winter with minimal external heating required for only few days in the KMC.

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Average daily ambient temperature in the KMC from November - February

	T2M	Temperature at 2 meters
	TS	Earth skin temperature

Date	T2M	TS	Date	T2M	TS	Date	T2M	TS	Date	T2M	TS
2018 10 31	16.32	14.68	2018 12 01	11.80	10.60	2019 01 01	8.67	5.42	2019 02 01	10.55	9.16
2018 11 01	16.26	15.01	2018 12 02	11.25	10.03	2019 01 02	8.07	5.12	2019 02 02	10.20	8.51
2018 11 02	15.39	14.22	2018 12 03	11.18	9.53	2019 01 03	6.98	4.87	2019 02 03	10.50	8.43
2018 11 03	14.35	13.36	2018 12 04	11.69	9.77	2019 01 04	7.60	5.26	2019 02 04	11.09	8.71
2018 11 04	14.22	12.74	2018 12 05	11.22	9.80	2019 01 05	8.78	6.14	2019 02 05	11.65	9.03
2018 11 05	14.23	12.98	2018 12 06	10.59	9.75	2019 01 06	8.92	6.78	2019 02 06	11.69	9.88
2018 11 06	13.52	11.82	2018 12 07	9.42	8.01	2019 01 07	6.68	5.10	2019 02 07	10.78	9.70
2018 11 07	13.09	11.17	2018 12 08	9.98	7.88	2019 01 08	8.36	6.31	2019 02 08	10.05	10.01
2018 11 08	13.40	11.09	2018 12 09	10.19	8.11	2019 01 09	8.43	6.68	2019 02 09	6.01	4.48
2018 11 09	13.58	11.29	2018 12 10	10.31	7.98	2019 01 10	8.18	5.83	2019 02 10	6.54	4.68
2018 11 10	13.16	11.84	2018 12 11	9.88	8.07	2019 01 11	8.20	6.28	2019 02 11	9.45	7.20
2018 11 11	13.35	11.95	2018 12 12	9.99	8.41	2019 01 12	8.70	6.24	2019 02 12	10.12	7.99
2018 11 12	13.67	12.58	2018 12 13	9.67	8.18	2019 01 13	9.08	6.49	2019 02 13	11.94	9.55
2018 11 13	13.22	12.52	2018 12 14	8.89	7.69	2019 01 14	8.23	6.39	2019 02 14	12.98	11.14
2018 11 14	13.19	12.52	2018 12 15	9.67	7.24	2019 01 15	8.37	5.88	2019 02 15	11.08	10.17
2018 11 15	13.32	12.85	2018 12 16	10.72	7.22	2019 01 16	9.90	6.34	2019 02 16	9.06	8.01
2018 11 16	12.72	11.60	2018 12 17	11.82	8.19	2019 01 17	9.88	7.38	2019 02 17	8.91	8.38
2018 11 17	12.06	10.75	2018 12 18	9.04	6.96	2019 01 18	9.09	7.05	2019 02 18	9.78	8.52
2018 11 18	11.82	10.19	2018 12 19	8.36	6.30	2019 01 19	9.11	6.87	2019 02 19	9.77	9.42
2018 11 19	11.76	9.95	2018 12 20	9.87	6.79	2019 01 20	9.71	7.54	2019 02 20	11.85	9.87
2018 11 20	12.28	10.01	2018 12 21	9.08	6.32	2019 01 21	10.43	8.12	2019 02 21	13.50	11.44
2018 11 21	12.16	9.97	2018 12 22	8.89	6.11	2019 01 22	10.66	8.86	2019 02 22	15.21	13.62
2018 11 22	12.66	10.65	2018 12 23	10.35	7.33	2019 01 23	9.00	9.00	2019 02 23	13.33	12.64
2018 11 23	13.68	11.36	2018 12 24	9.96	7.35	2019 01 24	8.63	8.25	2019 02 24	12.73	11.91
2018 11 24	13.00	10.74	2018 12 25	8.91	6.20	2019 01 25	8.80	8.39	2019 02 25	10.61	11.02
2018 11 25	13.60	10.74	2018 12 26	8.05	5.14	2019 01 26	8.30	8.37	2019 02 26	10.54	10.80
2018 11 26	13.81	10.94	2018 12 27	5.96	3.72	2019 01 27	8.72	8.19	2019 02 27	9.76	10.05
2018 11 27	13.41	11.00	2018 12 28	5.66	3.58	2019 01 28	7.46	7.19	2019 02 28	6.85	6.85
2018 11 28	13.82	11.13	2018 12 29	6.15	3.49	2019 01 29	6.24	5.03			
2018 11 29	14.05	12.23	2018 12 30	8.69	4.82	2019 01 30	8.10	6.06			
2018 11 30	13.06	11.69	2018 12 31	8.91	5.30	2019 01 31	10.09	8.05			

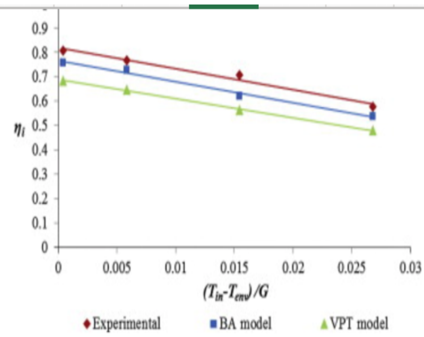
Daily Solar Insolation on the KMC: November 2018 - February 2019

Solar insolation incident on a horizontal surface									
Date	KWh/m2/day	Date	KWh/m2/day	Date	KWh/m2/day	Date	KWh/m2/day		
2018 11 01	5.02	2018 12 01	3.49	2019 01 01	4.25	2019 02 01	3.78	2019 03 01	6.00
2018 11 02	5.02	2018 12 02	3.72	2019 01 02	3.90	2019 02 02	4.83	2019 03 02	4.48
2018 11 03	4.93	2018 12 03	3.58	2019 01 03	4.07	2019 02 03	5.09	2019 03 03	4.45
2018 11 04	5.06	2018 12 04	3.53	2019 01 04	4.02	2019 02 04	5.12	2019 03 04	5.75
2018 11 05	4.98	2018 12 05	2.95	2019 01 05	3.97	2019 02 05	5.06	2019 03 05	5.36
2018 11 06	5.09	2018 12 06	4.16	2019 01 06	4.21	2019 02 06	4.67	2019 03 06	6.05
2018 11 07	5.05	2018 12 07	3.75	2019 01 07	2.65	2019 02 07	0.85	2019 03 07	6.20
2018 11 08	4.92	2018 12 08	4.03	2019 01 08	4.17	2019 02 08	2.69	2019 03 08	5.48
2018 11 09	4.74	2018 12 09	3.99	2019 01 09	3.95	2019 02 09	3.15	2019 03 09	5.93
2018 11 10	4.31	2018 12 10	4.16	2019 01 10	3.15	2019 02 10	5.33	2019 03 10	6.28
2018 11 11	4.46	2018 12 11	4.20	2019 01 11	3.73	2019 02 11	4.76	2019 03 11	6.39
2018 11 12	4.44	2018 12 12	4.10	2019 01 12	4.00	2019 02 12	4.84	2019 03 12	6.40
2018 11 13	4.23	2018 12 13	4.06	2019 01 13	4.37	2019 02 13	5.15	2019 03 13	6.54
2018 11 14	4.22	2018 12 14	3.91	2019 01 14	4.38	2019 02 14	2.84	2019 03 14	4.41
2018 11 15	4.14	2018 12 15	4.30	2019 01 15	4.32	2019 02 15	2.96	2019 03 15	5.02
2018 11 16	4.56	2018 12 16	4.33	2019 01 16	4.39	2019 02 16	3.25	2019 03 16	6.57
2018 11 17	4.54	2018 12 17	1.81	2019 01 17	4.03	2019 02 17	4.44	2019 03 17	6.56
2018 11 18	4.30	2018 12 18	1.79	2019 01 18	4.32	2019 02 18	4.23	2019 03 18	5.07
2018 11 19	3.83	2018 12 19	4.03	2019 01 19	4.03	2019 02 19	3.95	2019 03 19	6.00
2018 11 20	4.24	2018 12 20	3.79	2019 01 20	4.39	2019 02 20	5.35	2019 03 20	6.16
2018 11 21	3.86	2018 12 21	3.89	2019 01 21	4.56	2019 02 21	5.45	2019 03 21	6.52
2018 11 22	4.32	2018 12 22	3.45	2019 01 22	3.85	2019 02 22	5.43	2019 03 22	6.59
2018 11 23	4.40	2018 12 23	4.17	2019 01 23	1.21	2019 02 23	5.59	2019 03 23	6.84
2018 11 24	4.01	2018 12 24	4.21	2019 01 24	4.57	2019 02 24	3.13	2019 03 24	6.74
2018 11 25	4.43	2018 12 25	4.26	2019 01 25	3.66	2019 02 25	5.09	2019 03 25	5.93
2018 11 26	4.35	2018 12 26	3.97	2019 01 26	2.29	2019 02 26	5.88	2019 03 26	4.10
2018 11 27	4.39	2018 12 27	3.74	2019 01 27	3.72	2019 02 27	2.29	2019 03 27	6.92
2018 11 28	4.11	2018 12 28	3.79	2019 01 28	4.33	2019 02 28	3.44	2019 03 28	6.55
2018 11 29	4.25	2018 12 29	4.32	2019 01 29	4.11			2019 03 29	4.93
2018 11 30	3.43	2018 12 30	4.30	2019 01 30	4.96			2019 03 30	3.57
		2018 12 31	4.31	2019 01 31	3.23			2019 03 31	6.19

SWH system output calculation

SWH system output calculation for December

		Collector efficiency		
Tube length	1899mm	Jan	0.75	
Tube diameter	58mm	Feb	0.73	
Specific heat	4200 J/KgC	Nov	0.75	
Water storag	300 litres	Dec	0.74	
Number of t	30			
Absorptivity	94%			
Tin= Temperature of the inlet water				
Tenv= Tempearure of the environment				
Efficiency (n)= (Tin -TENV)/G				
Aperture area m2=		4.923		
Normalised area = Aperture area x efficiency x absorbtivity				
Aperture area m2=		7.38	(75% of TSA considered)	
Storage area	3.6	l=3 d=0.36		0.68
Loss	0.5	W/m2K		
heat loss hour	10			



								s=4200		dt=Q/ms	for 300l		(x-40)	Available he	Heat loss
		Air temperat	Temperature at T2M		Kwh/m2day	m2	Kwh (max)	ms(J/oC)	ms (kWh)	wh(max)/ms	fi hot water)	Twater	dt	Q=msdt	kWh
2018 12 01	3.49	10.9	11.8	3.49	4.17	3.4244388	14.27991	1260000	0.35	40.799742	52.599742	40	12.599742	4.4099098	0.5076
2018 12 02	3.72	9.8	11.25	3.72	4.4		15.067531			43.050088	54.300088		14.300088	5.0050307	0.5175
2018 12 03	3.58	9	11.18	3.58	4.26		14.588109			41.680312	52.860312		12.860312	4.5011093	0.51876
2018 12 04	3.53	9	11.69	3.53	4.21		14.416887			41.191107	52.881107		12.881107	4.5083873	0.50958
2018 12 05	2.95	9	11.22	2.95	3.63		12.430713			35.516322	46.736322		6.7363224	2.3577128	0.51804
2018 12 06	4.16	9.2	10.59	4.16	4.84		16.574284			47.355097	57.945097		17.945097	6.2807838	0.52938
2018 12 07	3.75	9.2	9.42	3.75	4.43		15.170264			43.343611	52.763611		12.763611	4.4672639	0.55044
2018 12 08	4.03	7.2	9.98	4.03	4.71		16.129107			46.083162	56.063162		16.063162	5.6221067	0.54036
2018 12 09	3.99	7.4	10.19	3.99	4.67		15.992129			45.691798	55.881798		15.881798	5.5586292	0.53658
2018 12 10	4.16	18	10.31	4.16	4.84		16.574284			47.355097	57.665097		17.665097	6.1827838	0.53442
2018 12 11	4.20	6.6	9.88	4.2	4.88		16.711261			47.746461	57.626461		17.626461	6.1692613	0.54216
2018 12 12	4.10	6.6	9.99	4.1	4.78		16.368817			46.76805	56.75805		16.75805	5.8653175	0.54018
2018 12 13	4.06	6	9.67	4.06	4.74		16.23184			46.376685	56.046685		16.046685	5.6163399	0.54594
2018 12 14	3.91	6	8.89	3.91	4.59		15.718174			44.909069	53.799069		13.799069	4.8296741	0.55998
2018 12 15	4.30	5.8	9.67	4.3	4.98		17.053705			48.724872	58.394872		18.394872	6.4382052	0.54594
2018 12 16	4.33	5.8	10.72	4.33	5.01		17.156438			49.018395	59.738395		19.738395	6.9084384	0.52704
2018 12 17	1.81	8	11.82	1.81	2.49		8.5268526			24.362436	36.182436		-3.817564	-1.3361474	0.50724
2018 12 18	1.79	8.8	9.04	1.79	2.47		8.4583638			24.166754	33.206754		-6.7932462	-2.3776362	0.55728
2018 12 19	4.03	5.7	8.36	4.03	4.71		16.129107			46.083162	54.443162		14.443162	5.0551067	0.56952
2018 12 20	3.79	9.8	9.87	3.79	4.47		15.307241			43.734976	53.604976		13.604976	4.7617414	0.54234
2018 12 21	3.89	9.9	9.08	3.89	4.57		15.649685			44.713387	53.793387		13.793387	4.8276853	0.55656
2018 12 22	3.45	5.6	8.89	3.45	4.13		14.142932			40.408378	49.298378		9.2983778	3.2544322	0.55998
2018 12 23	4.17	6.2	10.35	4.17	4.85		16.608528			47.452938	57.802938		17.802938	6.2310282	0.5337
2018 12 24	4.21	6	9.96	4.21	4.89		16.745506			47.844302	57.804302		17.804302	6.2315057	0.54072
2018 12 25	4.26	5.8	8.91	4.26	4.94		16.916728			48.333508	57.243508		17.243508	6.0352277	0.55962
2018 12 26	3.97	5.5	8.05	3.97	4.65		15.92364			45.496115	53.546115		13.546115	4.7411404	0.5751
2018 12 27	3.74	4.4	5.96	3.74	4.42		15.136019			43.24577	49.20577		9.20577	3.2220195	0.61272
2018 12 28	3.79	3.3	5.66	3.79	4.47		15.307241			43.734976	49.394976		9.3949755	3.2882414	0.61812
2018 12 29	4.32	3.1	6.15	4.32	5		17.122194			48.920554	55.070554		15.070554	5.274694	0.6093
2018 12 30	4.30	2.8	8.69	4.3	4.98		17.053705			48.724872	57.414872		17.414872	6.0952052	0.56358
2018 12 31	4.31	3	8.91	4.31	4.99		17.08795			48.822713	57.732713		17.732713	6.2064496	0.55962
														129.24235	16.9893

SWH system output calculation for January

2019 01 01	4.25	3.5	8.67	4.25	5.07	3.470715	17.596525		26.378703			50.275786	58.945786		18.945786	6.6310251	0.56394
2019 01 02	3.90	4	8.07	3.9	4.72		16.381775		24.557688			46.805071	54.875071		14.875071	5.2062748	0.57474
2019 01 03	4.07	4	6.98	4.07	4.89		16.971796		25.442181			48.490847	55.470847		15.470847	5.4147964	0.59436
2019 01 04	4.02	4	7.6	4.02	4.84		16.798261		25.182036			47.99503	55.59503		15.59503	5.4582606	0.5832
2019 01 05	3.97	4	8.78	3.97	4.79		16.624725		24.921891			47.499214	56.279214		16.279214	5.6977249	0.56196
2019 01 06	4.21	3.4	8.92	4.21	5.03		17.457696		26.170587			49.879133	58.799133		18.799133	6.5796965	0.55944
2019 01 07	2.65	7.4	6.68	2.65	3.47		12.043381		18.054063			34.40966	41.08966		1.0896601	0.381381	0.59976
2019 01 08	4.17	6.8	8.36	4.17	4.99		17.318868		25.962471			49.48248	57.84248		17.84248	6.2448679	0.56952
2019 01 09	3.95	6.2	8.43	3.95	4.77		16.555311		24.817833			47.300887	55.730887		15.730887	5.5058106	0.56826
2019 01 10	3.15	5.6	8.18	3.15	3.97		13.778739		20.655513			39.367824	47.547824		7.5478244	2.6417386	0.57276
2019 01 11	3.73	4.4	8.2	3.73	4.55		15.791753		23.673195			45.119295	53.319295		13.319295	4.6617533	0.5724
2019 01 12	4.00	4.9	8.7	4	4.82		16.728846		25.077978			47.796704	56.496704		16.496704	5.7738463	0.5634
2019 01 13	4.37	5.2	9.08	4.37	5.19		18.013011		27.003051			51.465745	60.545745		20.545745	7.1910109	0.55656
2019 01 14	4.38	5	8.23	4.38	5.2		18.047718		27.05508			51.564909	59.794909		19.794909	6.928218	0.57186
2019 01 15	4.32	5.8	8.37	4.32	5.14		17.839475		26.742906			50.969929	59.339929		19.339929	6.7689751	0.56934
2019 01 16	4.39	6	9.9	4.39	5.21		18.082425		27.107109			51.664072	61.564072		21.564072	7.5474252	0.5418
2019 01 17	4.03	5	9.88	4.03	4.85		16.832968		25.234065			48.094194	57.974194		17.974194	6.2909678	0.54216
2019 01 18	4.32	5.8	9.09	4.32	5.14		17.839475		26.742906			50.969929	60.059929		20.059929	7.0209751	0.55638
2019 01 19	4.03	7	9.11	4.03	4.85		16.832968		25.234065			48.094194	57.204194		17.204194	6.0214678	0.55602
2019 01 20	4.39	7.2	9.71	4.39	5.21		18.082425		27.107109			51.664072	61.374072		21.374072	7.4809252	0.54522
2019 01 21	4.56	7	10.43	4.56	5.38		18.672447		27.991602			53.349848	63.779848		23.779848	8.3229467	0.53226
2019 01 22	3.85	6.6	10.66	3.85	4.67		16.208239		24.297543			46.309254	56.969254		16.969254	5.9392391	0.52812
2019 01 23	1.21	6	9	1.21	2.03		7.0455515		10.561887			20.130147	29.130147		-10.86985	-3.804449	
2019 01 24	4.57	6.2	8.63	4.57	5.39		18.707154		28.043631			53.449011	62.079011		22.079011	7.7276539	0.56466
2019 01 25	3.66	8.8	8.8	3.66	4.48		15.548803		23.308992			44.425152	53.225152		13.225152	4.6288032	0.5616
2019 01 26	2.29	7	8.3	2.29	3.11		10.793924		16.181019			30.839782	39.139782		-0.860218	-0.301076	
2019 01 27	3.72	6	8.72	3.72	4.54		15.757046		23.621166			45.020132	53.740132		13.740132	4.8090461	0.56304
2019 01 28	4.33	5	7.46	4.33	5.15		17.874182		26.794935			51.069092	58.529092		18.529092	6.4851823	0.58572
2019 01 29	4.11	5.5	6.24	4.11	4.93		17.110625		25.650297			48.8875	55.1275		15.1275	5.294625	0.60768
2019 01 30	4.96	7.2	8.1	4.96	5.78		20.060733		30.072762			57.316379	65.416379		25.416379	8.8957327	0.5742
2019 01 31	3.23	8	10.09	3.23	4.05		14.056396		21.071745			40.161131	50.251131		10.251131	3.5878958	0.53838
					146.21											150.654	16.37874

Area Input for heating demand calculations

												[m²]		[m²]		
	Treated floor area	1	Treated floor area	5	x (	9.00	x	10.00	+		-	9.00			) =	405.0
	North windows	2	North windows													0.0
	East windows	3	East windows													29.3
	South windows	4	South windows	Please complete in Windows worksheet only!												0.0
	West windows	5	West windows													35.1
	Horizontal windows	6	Horizontal windows													0.0
	Exterior door	7	Exterior door	1	x (	1.00	x	2.10	+		-		) -		=	2.1
1	North wall	8	Exterior wall - Ambient	5	x (	9.00	x	2.17	+		-	1.76	) -	0.0	=	88.9
2	South wall	8	Exterior wall - Ambient	5	x (	9.00	x	2.17	+		-	1.76	) -	0.0	=	88.9
3	East wall	8	Exterior wall - Ambient	5	x (	10.00	x	2.17	+		-	2.34	) -	29.3	=	67.5
4	West wall	8	Exterior wall - Ambient	5	x (	10.00	x	2.17	+		-	2.76	) -	35.1	=	59.6
5					x (		x		+		-		) -	0.0	=	
6	Floor			4	x (	9.00	x	10.00	+		-		) -	0.0	=	360.0
7	Roof	10	Roof/Ceiling - Ambient	1	x (	9.00	x	10.00	+		-		) -	0.0	=	90.0
8	floor	11	Floor slab / Basement ceiling	1	x (	9.00	x	10.00	+		-		) -	0.0	=	90.0
9					x (		x		+		-		) -	0.0	=	
10	BeamEast	8	Exterior wall - Ambient	5	x (	10.00	x	0.23	+		-		) -	0.0	=	11.5
11	Beam West	8	Exterior wall - Ambient	5	x (	10.00	x	0.23	+		-		) -	0.0	=	11.5
12	Beam North	8	Exterior wall - Ambient	5	x (	9.00	x	0.23	+		-		) -	0.0	=	10.4
13	Beam South	8	Exterior wall - Ambient	5	x (	9.00	x	0.23	+		-		) -	0.0	=	10.4
14	Column East	8	Exterior wall - Ambient	20	x (	2.40	x	0.27	+		-		) -	0.0	=	13.0
15	Column West	8	Exterior wall - Ambient	20	x (	2.40	x	0.27	+		-		) -	0.0	=	13.0
16	Column North	8	Exterior wall - Ambient	15	x (	2.40	x	0.27	+		-		) -	0.0	=	9.7
17	Column South	8	Exterior wall - Ambient	15	x (	2.40	x	0.27	+		-		) -	0.0	=	9.7

Data input for windows sections

Quan-tity	Description	Deviation from north	Angle of inclination from the horizontal	Orien- tation	Width	Height	Selection from 'Areas' worksheet	Selection from 'Components' worksheet	Selection from 'Components' worksheet	Perpen-dicular radiation	Glazing	Frames (avg.)	$\Psi_{Glazing\ edge}$ (avg.)	left
		Degrees	Degrees		m	m		Sort: AS LIST	Sort: AS LIST	-	W/(m²K)	W/(m²K)	W/(mK)	
	North windows	0	90	North	1.830	1.370	1-North wall	92ud Single glazing	51ud PH-FRAMES: average thermal qu	0.87	5.80	0.75	0.040	1
	South Window	180	90	South	1.830	1.370	2-South wall	92ud Single glazing	51ud PH-FRAMES: average thermal qu	0.87	5.80	0.75	0.040	1
14	West window	270	90	West	1.830	1.370	4-West wall	92ud Single glazing	51ud PH-FRAMES: average thermal qu	0.87	5.80	0.75	0.040	1
10	East window	90	90	East	1.830	1.370	3-East wall	92ud Single glazing	51ud PH-FRAMES: average thermal qu	0.87	5.80	0.75	0.040	1
5	East window	90	90	East	0.700	1.200	3-East wall	92ud Single glazing	51ud PH-FRAMES: average thermal qu	0.87	5.80	0.75	0.040	1

Shading for windows

Horizon		Reveal		Overhang			
Height of the shading object	Horizontal distance	Window reveal depth	Distance from glazing edge to reveal	Overhang depth	Distance from upper glazing edge to overhang	Additional reduction factor winter shading	Additional reduction factor summer shading
m	m	m	m	m	m	%	%
h_{Hori}	d_{Hori}	o_{Reveal}	d_{Reveal}	o_{over}	d_{over}	$r_{other,w}$	$r_{other,s}$
			0.100			10%	0%
14.00	0.00	0.06	0.100			1000%	0%
14.00	4.00	0.06	0.100			30%	
14.00	2.00	0.06	0.100			30%	0%
14.00		0.06	0.100			50%	

Detailed calculation for heating demand, monthly basis

(This page displays the sums of the monthly method over the heating period)

Climate:	Standort 1	Interior temperature:	16 °C
Building:		Building type:	
Spec. Capacity:	60 Wh/(m²K)	Treated floor area A_{TFA}:	405.0 m²

Building assembly	Temperature zone	Area m²		U-Value W/(m²K)		Month. red. fac.		G_t kKh/a		kWh/a	per m² treated floor area
Exterior wall - Ambient	A	393.8	*	2.027	*	1.00	*	18	=	14470	35.73
Exterior wall - Ground	B		*		*	1.00	*		=		
Roof/Ceiling - Ambient	A	90.0	*	3.907	*	1.00	*	18	=	6375	15.74
Floor slab / Basement ceiling	B	90.0	*	1.185	*	1.00	*	-5	=	-557	-1.38
	A		*		*	1.00	*		=		
	A		*		*	1.00	*		=		
	X		*		*	0.75	*		=		
Windows	A	64.4	*	4.277	*	1.00	*	18	=	4991	12.32
Exterior door	A	2.1	*	2.000	*	1.00	*	18	=	76	0.19
Exterior TB (length/m)	A		*		*	1.00	*		=		0.00
Perimeter TB (length/m)	P		*		*	1.00	*		=		0.00
Ground TB (length/m)	B		*		*	1.00	*		=		0.00
Transmission heat losses Q_T									Total	25356	62.6 kWh/(m²a)

	A_{TFA} m²		Clear room height m		m³
Effective air volume V_V	405	*	2.40	=	972

	$n_{V,system}$ 1/h		η^*_{SHX}		η_{HR}		$n_{V,Res}$ 1/h		$n_{V,equi,fraction}$ 1/h
Effective air change rate Ambient nV,e	0.400	*(1-	0%	)*(1-	0.00	)+	0.098	=	0.498
Effective air change rate Ground nV,g	0.400	*	0%	*(1-	0.00	)		=	0.000

	V_V m³		$n_{V,equi,fraction}$ 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation losses ambient Q_V	972	*	0.498	*	0.33	*	18	=	2895	7.1
Ventilation losses ground $Q_{V,e}$	972	*	0.000	*	0.33	*	-9	=	0	0.0
Ventilation heat losses Q_V								Total	2895	7.1

		Q_T kWh/a		Q_V kWh/a		Reduction factor night/weekend saving		kWh/a	kWh/(m²a)
Total heat losses Q_L	(	25356	+	2895	) *	1.0	=	28250	69.8

Orientation of the area	Reduction factor See 'Windows' sheet		g-Value (perp. radiation)		Area m²		Global radiation kWh/(m²a)		kWh/a	kWh/(m²a)
North	0.00	*	0.00	*	0.0	*	409	=	0	
East	0.06	*	0.87	*	35.1	*	615	=	1161	
South	0.00	*	0.00	*	0.0	*	915	=	0	
West	0.07	*	0.87	*	29.3	*	615	=	1065	
Horizontal	0.00	*	0.00	*	0.0	*	837	=	0	
Sum opaque areas									25414	
Available solar heat gains Q_S								Total	27639	68.2

	kh/d		Length Heat. Period d/a		Spec. Power q_I W/m²		A_{TFA} m²		kWh/a	kWh/(m²a)
Internal heat gains Q_I	0.024	*	151	*	2.1	*	405.0	=	3082	7.6

			kWh/a	kWh/(m²a)
Free heat Q_F	Q_S + Q_I	=	30722	75.9
Ratio free heat to losses	Q_F / Q_L	=	1.09	
Utilisation factor heat gains η_G		=	58%	
Heat gains Q_G	η_G * Q_F	=	17885	44.2
Annual heating demand Q_H	Q_L - Q_G	=	10365	26

Operative temperature of all zones obtained from simulation

Date	Variables					
	Operative temperature, Deg-C	Operative temperature, Deg-C (Zone 2)	Operative temperature, Deg-C (Zone 3)	Operative temperature, Deg-C (Zone 4)	Operative temperature, Deg-C (Zone 5)	Operative temperature, Deg-C (Zone 6)
2019-01-01	17.01	13.24	13.96	14.02	13.66	13.55
2019-01-02	16.01	12.57	13.14	13.29	13.04	12.91
2019-01-03	15.7	13.07	13.26	13.54	13.34	12.85
2019-01-04	15.96	14.03	13.96	14.28	14.02	13.18
2019-01-05	16.23	14.47	14.4	14.59	14.31	13.53
2019-01-06	16.47	14.76	14.72	14.86	14.57	13.82
2019-01-07	16.69	14.85	14.85	15.04	14.72	13.75
2019-01-08	16.88	14.98	14.94	15.22	14.91	13.89
2019-01-09	17.06	15.12	15.1	15.43	15.03	14.01
2019-01-10	17.13	15.07	15.07	15.49	15.04	14.09
2019-01-11	17.51	15.72	15.56	16.02	15.74	14.73
2019-01-12	18.72	17.72	17.29	17.75	17.65	16.63
2019-01-13	19.39	17.84	17.73	18.05	17.82	16.8
2019-01-14	20.24	19.08	18.94	19.23	18.95	17.89
2019-01-15	20.28	18.14	18.53	18.47	18.09	17.49
2019-01-16	19.2	16.03	16.8	16.71	16.35	16.36
2019-01-17	18.54	15.55	16.18	16.15	15.87	15.78
2019-01-18	18.52	16.14	16.45	16.74	16.28	15.96
2019-01-19	18.54	16.13	16.38	16.63	16.4	15.91
2019-01-20	18.6	16.33	16.5	16.7	16.45	15.71
2019-01-21	18.17	15.51	15.8	15.98	15.62	14.76
2019-01-22	17.63	14.88	15.18	15.39	14.96	14.2
2019-01-23	17.24	14.59	14.87	15.08	14.68	13.97
2019-01-24	17.39	15.32	15.32	15.61	15.37	14.51
2019-01-25	18.05	16.58	16.36	16.84	16.41	15.29
2019-01-26	19.52	18.75	18.44	18.69	18.32	17.06
2019-01-27	19.73	17.7	18.06	17.92	17.51	16.53
2019-01-28	18.74	15.65	16.28	16.32	15.78	15.12
2019-01-29	18.07	15.11	15.53	15.77	15.24	14.56
2019-01-30	17.9	15.47	15.64	15.93	15.49	14.68
2019-01-31	17.95	15.81	15.87	16.19	15.72	14.68
mean	17.91	15.68	15.84	16.06	15.72	14.97
mean*744.0 h	13321.8	11668.8	11787.0	11950.4	11696.4	11140.2
min	15.7	12.57	13.14	13.29	13.04	12.85
max	20.28	19.08	18.94	19.23	18.95	17.89

Daily operative temperatures of January from simulation

Date	Variables					
	Operative temperature, Deg-C	Operative temperature, Deg-C (Zone 2)	Operative temperature, Deg-C (Zone 3)	Operative temperature, Deg-C (Zone 4)	Operative temperature, Deg-C (Zone 5)	Operative temperature, Deg-C (Zone 6)
2019-01-01	17.58	13.26	14.08	14.13	13.7	13.56
2019-01-02	16.58	12.59	13.27	13.4	13.07	12.92
2019-01-03	16.19	13.08	13.37	13.64	13.37	12.86
2019-01-04	16.35	14.05	14.06	14.37	14.06	13.19
2019-01-05	16.56	14.49	14.49	14.67	14.34	13.54
2019-01-06	16.76	14.73	14.76	14.88	14.56	13.8
2019-01-07	16.93	14.78	14.85	15.02	14.68	13.71
2019-01-08	17.12	14.97	14.98	15.24	14.91	13.87
2019-01-09	17.3	15.13	15.15	15.48	15.05	14.01
2019-01-10	17.39	15.08	15.13	15.55	15.06	14.09
2019-01-11	17.75	15.73	15.62	16.08	15.76	14.73
2019-01-12	18.83	17.77	17.34	17.82	17.69	16.65
2019-01-13	19.53	17.9	17.8	18.12	17.88	16.83
2019-01-14	20.32	19.12	18.99	19.3	18.99	17.93
2019-01-15	20.4	18.14	18.55	18.5	18.11	17.5
2019-01-16	19.51	16.02	16.85	16.75	16.36	16.37
2019-01-17	18.9	15.56	16.25	16.22	15.89	15.79
2019-01-18	18.84	16.16	16.53	16.81	16.31	15.97
2019-01-19	18.86	16.15	16.46	16.7	16.43	15.93
2019-01-20	18.91	16.35	16.58	16.78	16.49	15.73
2019-01-21	18.55	15.53	15.89	16.06	15.65	14.77
2019-01-22	18.06	14.89	15.28	15.48	15.0	14.21
2019-01-23	17.67	14.61	14.97	15.17	14.71	13.98
2019-01-24	17.76	15.35	15.43	15.71	15.41	14.53
2019-01-25	18.32	16.6	16.44	16.91	16.44	15.31
2019-01-26	19.61	18.77	18.49	18.73	18.34	17.07
2019-01-27	19.89	17.71	18.09	17.95	17.53	16.54
2019-01-28	19.09	15.66	16.34	16.38	15.8	15.13
2019-01-29	18.49	15.13	15.62	15.85	15.27	14.57
2019-01-30	18.3	15.48	15.73	16.02	15.52	14.69
2019-01-31	18.31	15.83	15.96	16.27	15.75	14.69
mean	18.21	15.7	15.91	16.13	15.75	14.98
mean*744.0 h	13551.5	11678.9	11840.2	11999.3	11715.0	11147.5
min	16.19	12.59	13.27	13.4	13.07	12.86
max	20.4	19.12	18.99	19.3	18.99	17.93

Daily operative temperature of January from simulation

Date	Mean air temperature, Deg-C	Operative temperature, Deg-C	Mean air temperature, Deg-C (Zone 2)	Operative temperature, Deg-C (Zone 2)	Mean air temperature, Deg-C (Zone 3)	Operative temperature, Deg-C (Zone 3)	Mean air temperature, Deg-C (Zone 4)	Operative temperature, Deg-C (Zone 4)	Mean air temperature, Deg-C (Zone 5)	Operative temperature, Deg-C (Zone 5)	Mean air temperature, Deg-C (Zone 6)	Operative temperature, Deg-C (Zone 6)
2019-01-01	17.84	17.41	15.27	15.41	16.19	16.21	15.94	16.04	13.73	13.9	13.36	13.62
2019-01-02	16.91	16.45	14.29	14.39	15.13	15.14	14.99	15.06	13.15	13.28	12.79	12.98
2019-01-03	16.58	16.11	14.23	14.29	14.7	14.7	14.77	14.81	13.48	13.55	12.77	12.92
2019-01-04	16.77	16.31	14.76	14.81	14.87	14.87	15.09	15.13	14.15	14.2	13.12	13.25
2019-01-05	16.96	16.51	15.09	15.15	15.14	15.15	15.24	15.3	14.36	14.43	13.48	13.58
2019-01-06	17.13	16.68	15.3	15.36	15.35	15.36	15.42	15.47	14.56	14.63	13.72	13.83
2019-01-07	17.29	16.84	15.45	15.52	15.53	15.54	15.63	15.68	14.68	14.75	13.58	13.74
2019-01-08	17.5	17.05	15.7	15.77	15.72	15.73	15.89	15.94	14.93	14.99	13.77	13.9
2019-01-09	17.69	17.25	15.9	15.98	15.91	15.92	16.17	16.23	15.08	15.15	13.9	14.05
2019-01-10	17.81	17.36	15.96	16.03	15.98	15.99	16.35	16.4	15.13	15.2	14.02	14.15
2019-01-11	18.22	17.75	16.45	16.48	16.32	16.33	16.78	16.8	15.87	15.88	14.77	14.79
2019-01-12	19.41	18.92	17.9	17.92	17.43	17.44	18.01	18.01	17.81	17.8	16.81	16.72
2019-01-13	20.02	19.57	18.39	18.44	18.2	18.21	18.55	18.59	17.9	17.95	16.85	16.87
2019-01-14	20.74	20.32	19.21	19.24	19.02	19.03	19.42	19.42	19.0	18.99	17.97	17.93
2019-01-15	20.81	20.35	18.78	18.86	19.14	19.15	19.03	19.11	18.04	18.14	17.41	17.52
2019-01-16	19.89	19.39	17.22	17.29	18.1	18.1	17.85	17.89	16.38	16.47	16.33	16.4
2019-01-17	19.29	18.79	16.53	16.59	17.4	17.38	17.17	17.2	15.94	16.03	15.74	15.84
2019-01-18	19.28	18.77	16.69	16.74	17.24	17.23	17.4	17.41	16.37	16.43	15.97	16.04
2019-01-19	19.25	18.78	16.83	16.89	17.27	17.27	17.42	17.45	16.44	16.53	15.88	15.97
2019-01-20	19.25	18.81	17.05	17.14	17.39	17.4	17.46	17.53	16.43	16.55	15.55	15.75
2019-01-21	18.83	18.43	16.7	16.81	17.11	17.13	17.11	17.21	15.61	15.76	14.52	14.81
2019-01-22	18.38	17.95	16.22	16.33	16.66	16.68	16.69	16.77	15.03	15.15	14.02	14.27
2019-01-23	18.02	17.58	15.85	15.95	16.28	16.29	16.31	16.39	14.74	14.86	13.83	14.03
2019-01-24	18.18	17.71	16.18	16.23	16.34	16.35	16.52	16.56	15.5	15.55	14.48	14.58
2019-01-25	18.8	18.31	16.97	16.99	16.86	16.86	17.36	17.36	16.57	16.56	15.36	15.37
2019-01-26	20.15	19.66	18.48	18.5	18.18	18.18	18.56	18.57	18.4	18.39	17.16	17.12
2019-01-27	20.26	19.83	18.25	18.36	18.59	18.61	18.41	18.48	17.43	17.55	16.39	16.56
2019-01-28	19.35	18.93	16.94	17.07	17.7	17.72	17.5	17.58	15.71	15.87	14.89	15.14
2019-01-29	18.78	18.34	16.43	16.53	17.03	17.04	17.01	17.09	15.27	15.4	14.38	14.61
2019-01-30	18.65	18.2	16.48	16.56	16.84	16.85	16.96	17.03	15.57	15.67	14.56	14.74
2019-01-31	18.67	18.23	16.65	16.73	16.87	16.88	17.06	17.13	15.79	15.87	14.56	14.74
mean	18.6	18.15	16.52	16.59	16.79	16.8	16.91	16.96	15.78	15.85	14.9	15.03
mean*744.0 h	13841.1	13501.6	12291.3	12345.1	12491.4	12498.1	12577.4	12615.5	11737.7	11795.0	11087.1	11179.1
min	16.58	16.11	14.23	14.29	14.7	14.7	14.77	14.81	13.15	13.28	12.77	12.92
max	20.81	20.35	19.21	19.24	19.14	19.15	19.42	19.42	19.0	18.99	17.97	17.93

Daily operative temperature from simulation

Daily operative temperature of December

Date	Variables					
	Operative temperature, Deg-C	Operative temperature, Deg-C (Zone 2)	Operative temperature, Deg-C (Zone 3)	Operative temperature, Deg-C (Zone 4)	Operative temperature, Deg-C (Zone 5)	Operative temperature, Deg-C (Zone 6)
2018-12-01	20.98	20.74	20.79	20.86	19.44	18.57
2018-12-02	20.71	20.19	20.31	20.34	18.65	17.82
2018-12-03	20.5	19.75	19.91	19.91	18.3	17.3
2018-12-04	20.21	19.2	19.43	19.39	17.6	16.67
2018-12-05	20.0	18.82	19.05	19.11	17.48	16.58
2018-12-06	19.87	18.58	18.8	18.95	17.44	16.45
2018-12-07	19.78	18.41	18.67	18.78	17.34	16.44
2018-12-08	19.55	18.12	18.42	18.5	17.0	16.22
2018-12-09	19.32	17.84	18.16	18.29	16.7	16.01
2018-12-10	19.12	17.58	17.93	18.04	16.55	15.88
2018-12-11	18.87	17.32	17.69	17.74	16.28	15.68
2018-12-12	18.94	17.41	17.67	17.9	16.81	16.0
2018-12-13	19.29	17.8	18.0	18.26	17.5	16.52
2018-12-14	19.42	17.93	18.16	18.39	17.37	16.43
2018-12-15	19.5	17.97	18.26	18.43	17.26	16.44
2018-12-16	19.76	18.25	18.44	18.76	17.94	17.26
2018-12-17	19.97	18.44	18.7	18.9	17.93	17.05
2018-12-18	20.04	18.52	18.77	19.02	17.99	17.11
2018-12-19	19.97	18.45	18.79	18.85	17.61	16.73
2018-12-20	19.3	17.79	18.22	18.18	16.24	15.36
2018-12-21	18.27	16.77	17.32	17.06	14.62	13.99
2018-12-22	17.82	16.32	16.72	16.65	15.02	14.56
2018-12-23	17.33	15.83	16.25	16.14	14.47	13.83
2018-12-24	17.44	15.98	16.21	16.43	15.33	14.35
2018-12-25	18.21	16.79	16.89	17.16	16.87	15.71
2018-12-26	18.56	17.1	17.3	17.41	16.76	15.73
2018-12-27	18.96	17.43	17.63	17.87	17.24	16.15
2018-12-28	19.66	18.18	18.25	18.75	18.29	17.08
2018-12-29	20.35	18.87	19.01	19.31	18.96	18.0
2018-12-30	20.07	18.48	18.89	18.88	17.48	16.62
2018-12-31	18.94	17.37	17.95	17.72	15.26	14.63
mean	19.38	18.01	18.28	18.39	17.09	16.23
mean*744.0 h	14417.3	13397.7	13599.1	13679.7	12713.4	12075.9
min	17.33	15.83	16.21	16.14	14.47	13.83
max	20.98	20.74	20.79	20.86	19.44	18.57

Daily operative temperature of January

Date	Variables					
	Operative temperature, Deg-C	Operative temperature, Deg-C (Zone 2)	Operative temperature, Deg-C (Zone 3)	Operative temperature, Deg-C (Zone 4)	Operative temperature, Deg-C (Zone 5)	Operative temperature, Deg-C (Zone 6)
2019-01-01	18.05	16.23	16.88	16.62	13.98	13.63
2019-01-02	17.16	15.3	15.9	15.73	13.41	13.02
2019-01-03	16.79	14.93	15.41	15.45	13.71	12.98
2019-01-04	16.87	15.06	15.41	15.6	14.32	13.31
2019-01-05	16.99	15.21	15.55	15.65	14.5	13.62
2019-01-06	17.11	15.34	15.67	15.76	14.68	13.85
2019-01-07	17.24	15.48	15.8	15.93	14.79	13.76
2019-01-08	17.41	15.66	15.96	16.16	15.02	13.92
2019-01-09	17.59	15.85	16.13	16.41	15.19	14.07
2019-01-10	17.7	15.96	16.22	16.59	15.24	14.17
2019-01-11	18.06	16.32	16.52	16.97	15.92	14.81
2019-01-12	19.07	17.36	17.43	18.01	17.81	16.73
2019-01-13	19.71	17.99	18.15	18.55	17.95	16.89
2019-01-14	20.39	18.79	18.93	19.36	19.01	17.95
2019-01-15	20.44	18.71	19.11	19.07	18.12	17.51
2019-01-16	19.71	17.76	18.37	18.14	16.49	16.4
2019-01-17	19.2	17.17	17.79	17.59	16.09	15.86
2019-01-18	19.16	17.12	17.62	17.75	16.51	16.06
2019-01-19	19.18	17.18	17.65	17.78	16.61	16.01
2019-01-20	19.23	17.29	17.74	17.86	16.64	15.79
2019-01-21	18.91	17.04	17.53	17.58	15.83	14.84
2019-01-22	18.48	16.66	17.14	17.18	15.22	14.3
2019-01-23	18.12	16.31	16.77	16.83	14.94	14.06
2019-01-24	18.2	16.42	16.76	16.96	15.64	14.62
2019-01-25	18.67	16.92	17.12	17.59	16.59	15.39
2019-01-26	19.8	18.04	18.18	18.58	18.4	17.14
2019-01-27	20.03	18.21	18.62	18.55	17.57	16.58
2019-01-28	19.35	17.46	18.04	17.92	15.93	15.17
2019-01-29	18.86	16.99	17.52	17.53	15.49	14.64
2019-01-30	18.7	16.87	17.31	17.43	15.75	14.77
2019-01-31	18.71	16.92	17.28	17.5	15.94	14.77
mean	18.54	16.73	17.11	17.25	15.91	15.05
mean*744.0 h	13797.5	12445.8	12732.8	12831.3	11838.9	11199.2
min	16.79	14.93	15.41	15.45	13.41	12.98
max	20.44	18.79	19.11	19.36	19.01	17.95