UNIVERSITY
OF GÄVLE

Department of Technology and Built Environment

ENERGY AUDIT OF A BUILDING

Energy Audit and Saving Analysis

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Preface

At the end of our final thesis project, looking back all the efforts we have done, there are so many people we want to say thanks to. Many difficulties which are out of expected have occurred, such as while the selecting the subject, measuring and collecting the datum, calculating and so on. Thanks to the help from our supervisor, professors in university, staffs in the companies, as well as our classmates, friends and support from our families, we can finally complete the thesis.

For those reasons, we really appreciate their patient encouragement and definite love.

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Meanwhile, we would like to thank Mr. Bengt Olsson and Cleas Bergstrom, who have been always very patient and provided all the important information we need.

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Special thanks to each other for the care and help during the one year's studying aboard. It is a rare and nice experience in our life time.

Finally, much grateful is given to our parents. Whenever happiness, sadness or hard time, you are always standing by, and never leave us alone.

Abstract

The typical residential building is located at the crossing of S. Centralgatan Street and Nedre Åkargatan Street in the city of Gavle. It is a quadrangle building of six floors with a yard in the middle. There are 180 apartments of five types in total, and at the first floor there is a kindergarten. There is a District Heating in the building and heating recovery system ventilation which use heat exchanger to reheat.

Several solutions are used for reducing the heat loss. In the first step, the heat loss and heat in has been calculated. There are several parameters that involve the heat loss and heat in of whole building, so each parameter in the energy balance equation is extracted and calculated. And then the Energy Balance Sheet has been built. Among the heat loss part, the transmission is 1237MWh, the hot tap water is 332MWh, the mechanical ventilation is 1041MWh, the natural ventilation is 325.7MWh.In the part of heat in, the DH is 1265.7MWh, the heat pump is 793MWh, the solar radiation is 562MWh, the internal heating is 315MWh.Later in the second step, after analyzing data of heat loss part, the improvements will be focused on the transmission and hot tap water parts because the heat loss in those two parts occupy the most. At the end of final step, the solutions have been discussed to optimize the heating system.

As conclusion, there are several suggested solutions. The total reduction of heat loss after adjustment is 163MWh, accounts 5.6% of originally heat loss. The heat loss of the building has been reduced from 2935.7MWh to 2772.7MWh.

Content

1. INTRODUCTION

1.1 World Energy Outlook

Energy is an important foundation resource of human society's development. However, the rapid-fold increase of energy consumption with the increasing development of world economy, world's population and the human being's living standards leads to increasingly fierce competition of energy resources and environmental pollution.

According to the IEA(International Energy Agency)'s forecast in the <World Energy Outlook 2004>,the world energy consumption will be increasing from 10.24 billion tons of oil equivalent in 2001 to 16.2 billion tons of oil equivalent in 2005,and the world energy consumption will increase by 54% in 2001-2025.

The depletion of global fossil energy is inevitable, and it will end up in the 21st century basically. As the data shown in the <BP Statistical Review of World Energy 2006>，the global oil explored reserve could provide production for 40 years or more, natural gas and coal will supply 65 years and 155 years. At the same time, the emissions of CO_2 will increase and how to reduce the emission of greenhouse gas will be a stern challenge.

With the increasing of world energy consumption, the emission of environment pollutant (as carbon dioxide, nitrogen oxide, dust particles) has been increased year by year, and the fossil energy does serious harm to the environment and global climate day by day. According to the IEA's statistics, the emission of world carbon dioxide was approximately 21.56 billion tons in 1990, amounted to 23.91 billion tons in 2001, estimated that will be 27.72 billion tons in 2010, amounted to 37.12 billion tons in 2025 and it averagely grows 1.85% per year.

The more stable, sustainable energy supply such as the renewable energy is required due to the worldwide decline of fossil energy supply.

Due to the use and development trend of world renewable energy source， the development of the wind energy, the solar energy and the biomass energy is much better than other conventional energy source. The cost of the wind power generation technology is much lower as the conventional energy source, therefore it becomes such clean energy technology which develops fastest in industrial production and it increases 27% per year.

The IEA's data shows that in strongly encourage renewable energy sources into the energy market conditions, to 2020 new and renewable energy (excluding large hydropower and traditional biomass energy) will account for 20 percent of global energy consumption, the proportion of renewable Energy in total energy consumption will reach 30 percent, from energy security or environmental requirements, renewable energy will become the strategic choice of new energy sources.

1.2 Energy audit

An energy audit is an inspection, survey and analysis of energy flows in a building, process or system，and the objective is to understand the energy dynamics of the system under study and make sure the high efficiency of energy using. Typically an energy audit is conducted to seek opportunities to reduce the amount of energy input into the system without negatively affecting the output(s). “The Energy Audit serves to identify all of the energy streams into a facility and to quantify energy use according to discrete functions, similar to the monthly closing statement of an accounting system”. When the object of study is an occupied building then reducing energy consumption while maintaining or improving human comfort, health and safety are of primary concern. Beyond simply identifying the sources of energy use, an energy audit seeks to prioritize the energy uses according to the greatest to least cost effective opportunities for energy savings.

The continuous energy monitoring which get though the energy audits of energy consumption in the past and present energy is a key step of energy saving and increasing the energy efficiency. Energy audit includes the following steps:

A．Data collection

Collect the history data of energy use and understand the situation of energy use is very important in assessing the building’s energy consumption. Such information can be collected through the energy bill and meter reading. In order to obtain a comprehensive analysis of the results, the monthly energy consumption data in the past three years or more is necessary at least.

B．Surveys and measurement

Through field surveys and measurement，the energy use of the building could be able to be known as currently as possible. Followed by analysis of the energy consumption data, the measures of improving the energy efficiency could be determined.

For example, the type of the windows, U-value coefficient and Calculation Factor, the lighting requirements and so on are noted. These information could be compared against the recommendations in the relevant Codes of Practices such as CP 13:1999 and CP 24:1999

C．Energy consumption benchmarks

Energy consumption benchmarks are different from energy consumption indicators. They are important tools of evaluating situation in different types of energy use. The energy consumption performance in same kind of building could be compared by the energy consumption benchmark。

Property managers can check the account of electrical equipments/system, check the energy consuming situation of each part, to find out if the energy efficiency is low or not and search for the way which can improve it. Energy auditing is a extremely useful energy management method. Through the way suggested in the energy auditing process, not only reducing the energy consumption, but also extending the lifetime of the equipment and save money. Energy auditing must be controlled by the professional technicians who have the housing equipment installation skills. According to the results technician write an energy auditing report to suggest a series of management

The effects of different energy saving measurements are difficult to be estimated because the energy balance and the relations between the different heat flows and different energy customers are very complicated.

The parameters that could be measured in the energy balance can be divided in some groups:

1. Transport of energy through the building envelope:

    -Transmission losses through walls, roof, floor, windows and doors

    -Heat transport due to infiltrations

    -Solar radiation through windows

2. Activities and equipments of generating internal heat:

    -Free heat due to people

    -Free heat due to lights, computers and all the equipments

3. Energy supplied to achieve the required indoor climate:

-Heat supply and loss

-Ventilation air

-Domestic hot water heating

Although all the parameters have not got the same importance, some of them are relatively small; all of them have been taken in consideration when running the energy audit.

1.3 Aim

The aim of the project is to improve the energy system of the building in order to reducing the heat consumption and saving energy and money. The simulation and optimization program has been used during the progress.

1.4 Location

The building is a residential building which is located at the crossing of S. Centralgatan and Nedre Åkargatan in Gavle. Gavle city is in the Middle East of Sweden and by the side of Baltic Sea. It is 180km far away from Stockholm.

Figure 1: The Building

1.5 Composition

The object in the project is a quadrangle residential building of six floors. There is a yard in the middle of the building.

There are 180 apartments in this building in total. Five types of apartments are available. More details are showed as following pictures.

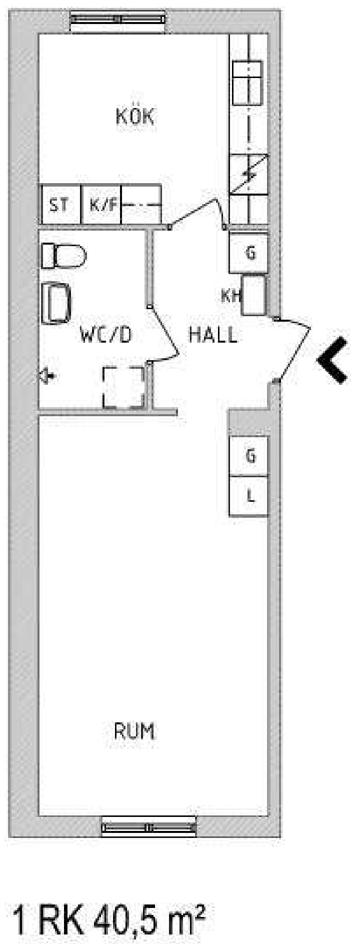
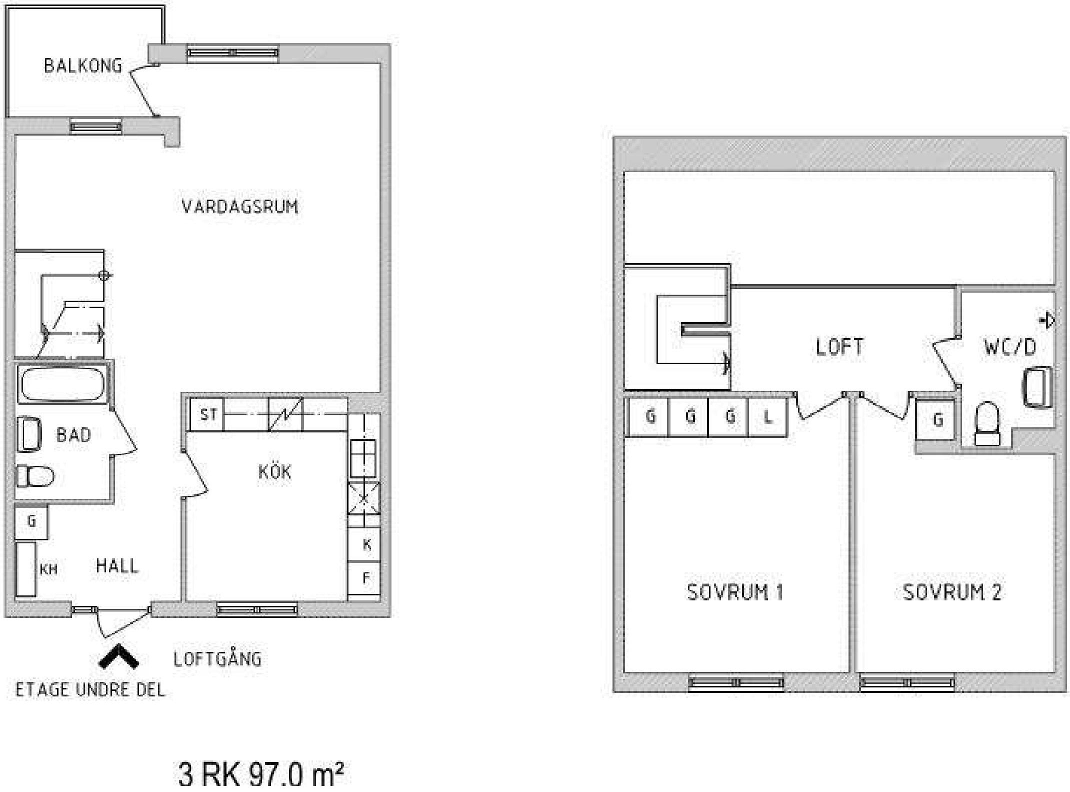
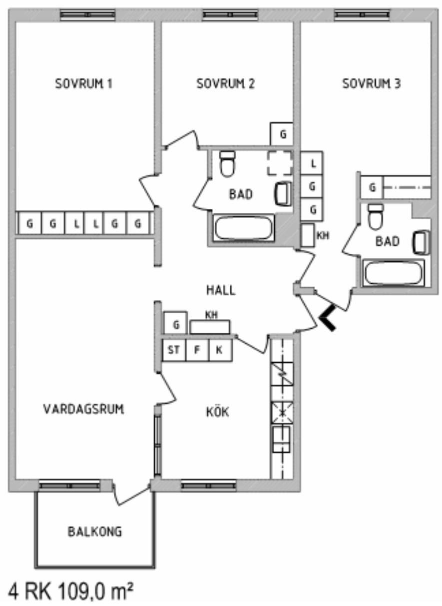


Figure 2: 1-room apartment, totally 32 apartments in the building

Figure 3: 2-room apartment, totally 48 apartments in the building



<u>Figure 4: 3-room apartment, totally 79 apartments in the building</u>



<u>Figure 5: 4-room apartment, totally 11 apartments in the building</u>

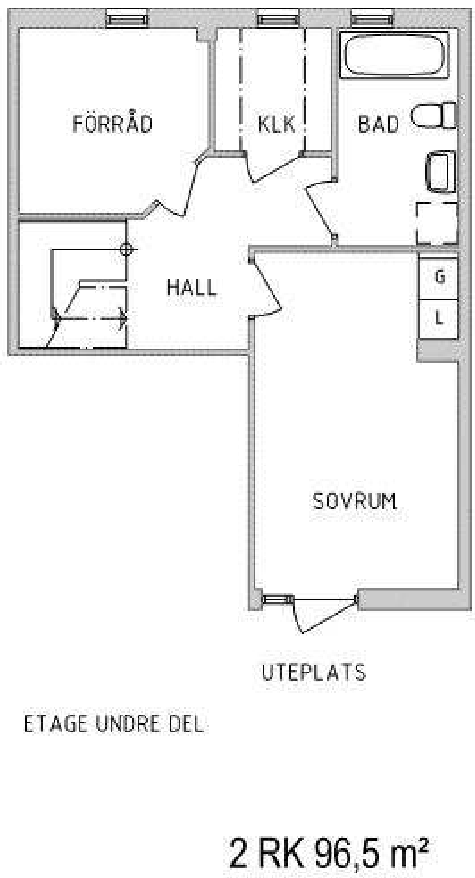


Figure 6: special need 2-room apartment, totally 10 apartments in the building

On the first floor besides Gate 72B, there is a kindergarten.

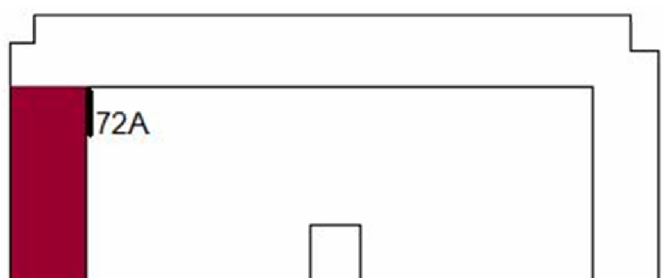


Figure 7: The position of the kindergarten

Figure 8: The kindergarten

2. Theories

2.1 General introduction

2.1.1 Indoor climate and HVAC system

Indoor climate indicates the balance of the interior thermal environment. People would feel comfortable and healthy in good indoor climate.

To keep the indoor climate beneficial, besides some established factors such as the outdoor climate and the building structure, it is important to bring in the HVAC system.

HVAC stands for “heating, ventilation and air conditioning”. It is somehow a control system in modern buildings which can keep comfortable thermal condition and help to create good air quality. HVAC would remove heat and dirty air out of the building when there is heat surplus, and would supply heat when there is heat deficit.

In Nordic countries just like Sweden, the weather is normally cold in most time, and the temperature during summer time is cool and comfortable. So it is unnecessary to use air condition in Sweden.

2.1.2 District Heating

District heating uses water that is centrally heated and distributed through a pipe-system to individual users in areas of high concentration of activities and housing.

The main form of heating system in Sweden is District Heating. There are many reasons to choose DH:

-Easy and flexible to produce heat

-Enables combined heat and power production

-Higher efficiency and lower costs

-Enables new heat sources, e.g. waste burning heat

2.1.3 Heat Pump

A heat pump can absorb heat from surroundings and transport heat from the heat source to the heat sink. The heat pump usually moves the heat form low temperature to high temperature, and it is actually a kind of heat lifting gear.

Here is the operation progress of heat pump:

Step 1: The over-heat liquid media evaporates into the gas media with absorbing the heat of the low temperature object in the evaporator.

Step 2: The gas media coming out from the evaporator has been compressed into high-temperature high pressure gas media.

Step 3: The high temperature high pressure gas media release the heat energy to the high temperature object in the condenser, and it turns into high-pressured liquid media at the same time.

Step 4: The high-pressured liquid media reduces pressure in the expansion, becomes the over-heated liquid media again, and then enters the evaporator as the step 1.

According to the different used heat sources, the heat pump has been divided into several types. Ground-source heat pump heat transfer system can be installed in a variety of structures. The closed-loop system is constituted of a series of pipeline which are buried in the mud, ponds or lakes. Ground-source heat pump loop can be built in drilled holes (vertical and horizontal loop) or ponds, lakes (ponds loop).

Vertical Loop:

Vertical loop system is inset the pipe into the vertical drilled hole, the advantage is smaller space requirements. The design of the underground loop needs to consider following factors: the total demand of heating and cooling, the space can be used and drilling environment. Although each vertical loop is different, but normally one bored hole (one loop) can take one ton of heating and cooling capacity. Holes are usually have a distance of 4.5 meters with each other, in order to minimize the influence among adjacent loop. The diameter of pipes is usually from 20 to 32 mm. And then use gravel or other slurries to fill bored hole from the bottom, to ensure a solid interface around pipeline, and guarantee the water from surface will not inrush into underground aquifers directly at the same time. After the completion of these processes, every pipeline in bored hole and level pipeline and header needs to be linked up. Usually connecting of parallel pipelines needs to be done by use of several headers.

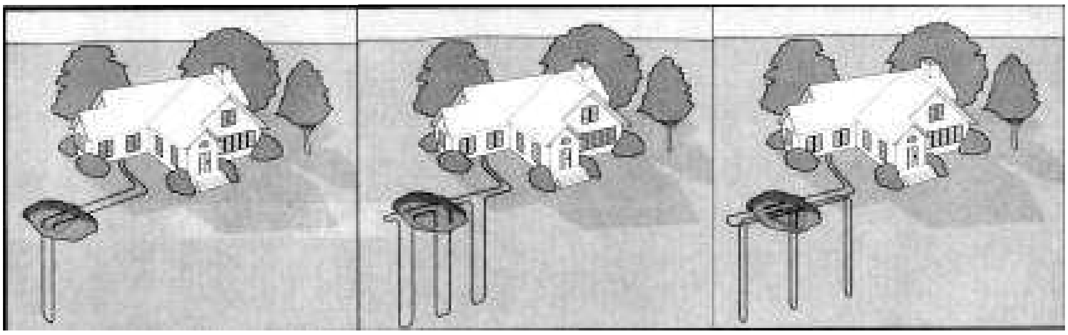


Figure 9: Vertical Loop Heat Pump

Horizontal:

There are two forms of horizontal heat exchanger which are single tube and multi-tube. The single tube horizontal heat exchanger will use larger space.

Although the space requiem of multi-tube horizontal heat exchanger will be decreased, there will correspond be a longer pipe to compromise the heat interference of adjacent pipelines. The cost of horizontal heat exchanger can be decreased due to the large use of construction equipment and construction personnel easy to find, and many families have big enough construction place. Besides the need of larger venues, there are other disadvantages of horizontal heat exchanger system which are: Performance instability (because of the shallow earth temperature and thermal characteristics changes with the season, the depth and the rainfall); high energy-consuming; decreasing in system efficiency.

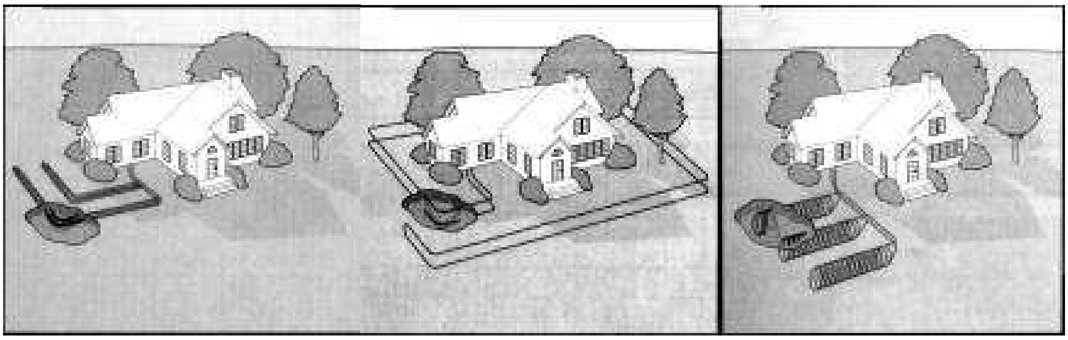


Figure 10: Horizontal Heat Pump

2.1.4 Ventilation

Though the summer in Sweden is short and cool, heat surplus should also be taken into consideration. To move heat surplus out of building and keep the indoor air quality, ventilation system is the most important and effective way.

There are two types of ventilation: natural ventilation and mechanical ventilation.

Natural ventilation refers to the normal air exchange between outdoor and indoor through natural way. For example, the opened windows, the fans in the kitchen and so on. There exists no forced factor during the air exchange process.

Mechanical ventilation (or forced ventilation) operates mechanically to realize the air exchange through a specific ventilation system. It removes heat, airborne pollutant, moisture and so on out of the building and fills in with fresh and clean air. Mechanical ventilation is mainly used in bathroom or kitchen.

2.1.5 Heat recovery

In mechanical ventilation system, both the exhaust air and the outdoor fresh air pass through the heat recovery ventilators (HRV), so HRV could gain heat from exhaust air and use it to pre-heat incoming fresh air. During this process, there would only exist heat transfer between the two air streams without being mixed together.

Typically, this process saves about 60%~80% of the energy by reducing heating requirements as well as needed energy.

To create and maintain a healthier indoor environment, HRV system is designed to change all the air at least once every two hours. It replaces the exhaust stale air with fresh and warm air, thus continually keeps a good indoor climate.

Recovery of heat by heat exchange can be done by heat exchangers. There are mainly two types of heat exchanger, which is recuperative and regenerative heat exchanger, as shown in the following figure:

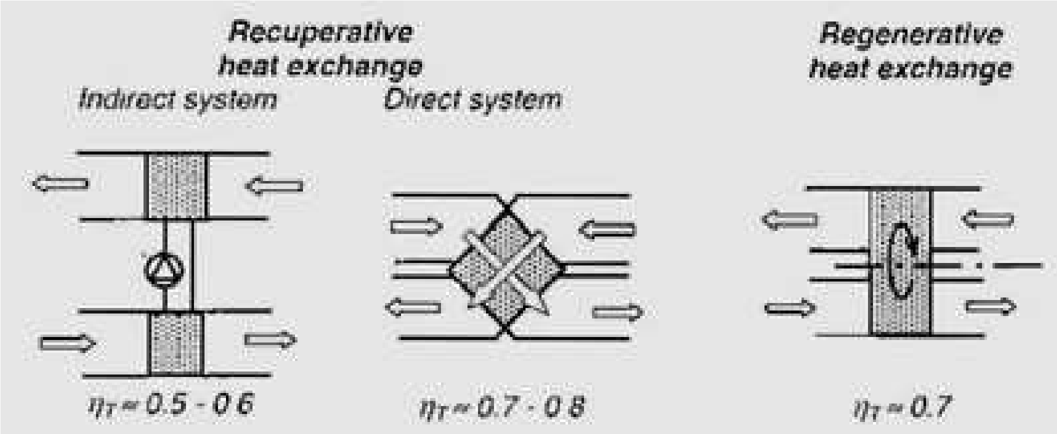


Figure 11: Classification of Heat Exchangers

In this building, the heat exchangers belong to indirect system of recuperative heat exchanger. And the efficiency of the heat exchanger is 50%.

The characteristics of heat exchanger are listed:

(1) Saving electricity. The heat exchanger could supply heat without electrically operated circulating water pump. The saving is up to 30%-100%.

(2) The area of the heat exchanger is small. So the investment could be saved up to 70%.

(3) The service life of the heat exchanger is long as 15 years.

2.2 Energy Balance

2.2.1 Energy Balance

Energy is the capacity of a physical system to do work. The famous law of conservation of energy, that is, First Law of Thermodynamics, points out that energy can never be created or destroyed, but only converted. The total energy of a system would always remain constant, but energy may transform to another kind of form.

It is important to analyze energy balance for the building's energy survey and saving. First, it can provide a general understanding of the processes and systems which result in the building's indoor climate and determine the energy usage of the building. Second, it could help supplying methods for analysis, evaluation and design of the building's indoor climate control systems, while determine the energy need of the building.

The heat balance of a building is defined by the following parameters:

- Transport of heat through the envelope of building
- Storage of heat in the building structure
- Internal generation of heat in the building

In the case of this building, the First Law of Thermodynamics also applies. Since there is no energy created or destroyed, the total energy of the building would always stay in balance. And the energy balance can be expresses as:

$$\text{Heat loss} = \text{Heat in}$$

The factors which result in heat loss as well as heat in are all listed in the following form:

Table 1: Parameters of Energy Balance

Heat Loss	**Transmission**	
	Ventilation	Mechanical
		Natural
	Hot tap water	
Heat In	**District Heating**	
	Solar Radiation	
	Internal Heat	
	Heat Pump	

Then the energy balance equation can be expressed as: $Q_{water} = \rho * C_p * V * T$ [1]

$$\underbrace{Q_{tran} + Q_{ven(Mech)} + Q_{ven(Natr)} + Q_{water}}_{\text{Heat Loss}} = \underbrace{Q_{DH} + Q_{solar} + Q_{\text{int}} + Q_{pump}}_{\text{Heat In}}$$

Now we can make the energy survey for each parameter of this equation. It is a clear and efficiency way to analyze the energy balance of the whole building.

2.2.2 Heat Loss: Transport of heat through the envelope of building

When the outdoor temperature, t_0(℃), is lower than the room temperature, t_r(℃), the building will lose heat to its surroundi ngs. The two main forms of transport are transmission and infiltration through the envelope of building, such as the outside walls, the windows and doors and the roof.

a. Transmission:

The outdoor and indoor temperature cannot always be the same. For example, in the winter, the indoor temperature is about 21℃ due to the heating system, but the outdoor temperature may be -20℃. The building is not sealed, so there would surely be a heat flux because of the temperature difference.

Here, the heat flux through the structure of building envelope due to temperature difference is transmission. And the equation for transmission is:

$$P_{tran} = \sum U * A * (t_r - t_o) \qquad [2]$$

-U is heat transmission coefficient (W/m^2·℃)

-A is the area of building envelope (m^2)

-(t_r – t_o) the temperature difference between outdoor and room temperature(℃)

The q_{degree} value is introduced to calculate the total energy of heat loss due to transmission. It could be obtained from the duration diagram varying with the location between two temperatures.

Therefore, the equation for the total energy of heat loss due to transmission is:

$$Qtran = U * A * Q\deg ree \qquad [3]$$

b. Ventilation:

Ventilation refers to the introduction of outdoor fresh air into the building. As it mentioned above, there are mechanically and natural ventilation.

Mechanically ventilation is operated by the ventilation systems. In this part, the heat loss can be calculated by the air flow data.

Natural ventilation is due to the accidental air introduction because of cracks in the building envelope and opened doors and windows. So it is not possible to calculate the heat loss of this part. But because the quantity of the heat loss equals to heat in, the natural ventilation heat loss can be calculated through the equation of energy balance.

The equation of mechanical ventilation：

$$Q_{ven} = V_{ven} * \rho * C_p * Q_{degree} \qquad [4]$$

-V_{ven} is the airflow due to infiltration (m^3/s)

-P is the density of air (Kg/m^3)

-C_p is the specific heat capacity of air (J/Kg·℃)

2.2.3 Storage of heat in the building structure

The building structure can store heat. So even if there is no heating system in a building, the room temperature would not vary with outdoor temperature immediately. Mentionable, heat storage plays a vital role to compensate the temperature difference – the building structure as well as the furniture absorb heat during daytime and emit heat at night.

2.2.4 Internal Generation of Heat

Solar irradiation and radiated heat from lights, people and equipment are two main forms of internal generation of heat. This heat compensates heat loss.

One of the most important sources of heat for a building is solar radiation. It would contribute no less than 70% energy for heat storage. The orientation of the building and the type of windows should be considered during this part's calculation. Because of the sun's orbit, the solar radiation of each face of the building would not be the same. And due to difference types of windows, such as 2-glass and 3-glass windows, the coefficient of window varies. All these factors should be taken into consideration while analyze the solar radiation.

And another source is radiated heat from lights, people and equipment. People's activities in the building would emit heat. All the electrical equipments such as computers, lights, refrigerators, televisions and so on will all generate heat, in other words, convert electricity into heat.

3 Calculation and results

3.1 Heat in

3.1.1. District Heating

Table 2: Energy consumption data of year 2007

Year 2007			
Energi for heating	1265,700 MWh		
Heatpump-produktion	793,000 MWh		
Heatpump-electriciti	238,855 MWh (estimated)		
Electriciti for the building (not apartment)	706,305 MWh		
Waterconsumptions		15000	m3
Heatwater: Count with 38% of totalwater	38%	5700	m3
"Graddagar" 2007	3723		
"Normalår"	4131		

Refer to the bill above, it can be found that the energy for DH is 1265.7 MWh in year 2007.

3.1.2. Solar radiation

The solar irradiation passing through windows contributes a lot to the heat storage. The heat from solar irradiation in the daytime is absorbed in floors, walls and furniture, and transformed to heat before it affects the heat balance of the room.

To calculate the solar radiation, first we should analyze the building’s direction. There are four faces for the windows of the building:

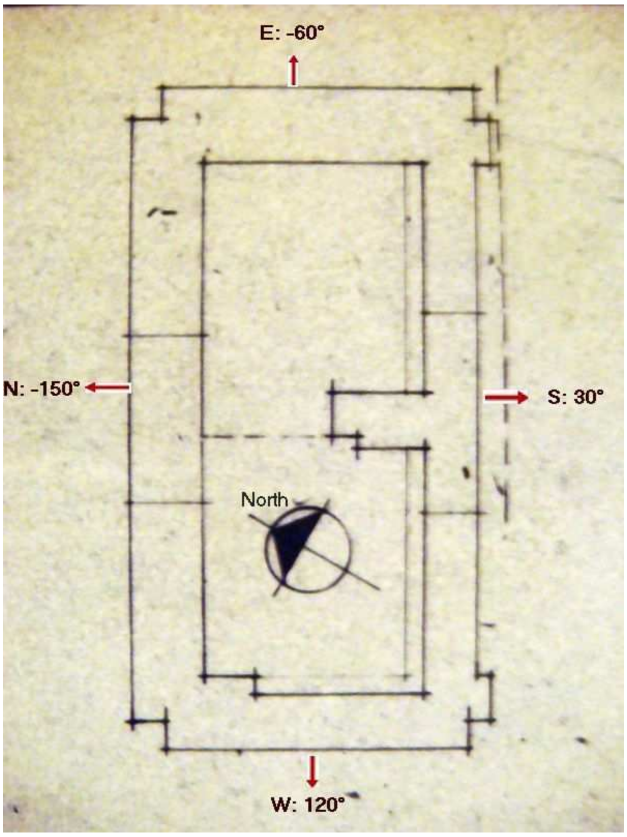


Figure 12: Direction of the building

Then it can be found that the four faces of the building are:

Table 3: Angles of four faces of the building

North	East	South	West
-150°	-60°	30°	120°

The equation for calculating the solar radiation is:

$$Q_{solar} = (W_{h/m^2}) * A_{window} * Calculation\_Factor \qquad [5]$$

- A_{window} is the area of windows (m^2)

- Calculation_factor depends on different window types

-The value of (Wh/m^2) is shown in the table below:

Table 4: The value of (Wh/m^2)

Månad	Horisont-avskärmning.°	Vertikala ytans orientering N −180	−150	−120	E −90	−60	−30	S 0	30	60	W 90	120	150
Latitud 60 ° N													
Januari	0	130	130	160	550	1 440	2 360	2 710	2 360	1 440	550	160	130
	10	70	70	70	90	140	180	200	180	140	90	70	70
Februari	0	370	370	640	1 550	2 900	4 280	4 880	4 280	2 900	1 550	640	370
	10	340	340	400	1 030	2 240	3 530	4 020	3 530	2 240	1 030	400	340
Mars	0	730	900	1 720	3 050	4 520	5 740	6 320	5 740	4 520	3 050	1 720	900
	10	710	730	1 290	2 460	3 920	5 290	5 970	5 290	3 920	2 460	1 290	730
April	0	1 350	1 990	3 320	4 750	5 850	6 370	6 410	6 370	5 850	4 750	3 320	1 990
	10	1 170	1 640	2 810	4 220	5 420	6 160	6 390	6 160	5 420	4 220	2 810	1 640
Maj	0	2 350	3 050	4 460	5 630	6 150	5 980	5 730	5 980	6 150	5 630	4 460	3 050
	10	1 840	2 570	3 910	5 130	5 840	5 920	5 710	5 920	5 840	5 130	3 910	2 570
Juni	0	3 210	3 870	5 230	6 190	6 350	5 820	5 460	5 820	6 350	6 190	5 230	3 870
	10	2 420	3 180	4 570	5 650	6 070	5 790	5 430	5 790	6 070	5 650	4 570	3 180
Juli	0	2 830	3 510	4 910	5 960	6 280	5 820	5 580	5 890	6 280	5 960	4 910	3 510
	10	2 270	3 020	4 410	5 540	6 050	5 870	5 560	5 870	6 050	5 540	4 410	3 020
Augusti	0	1 700	2 380	3 720	5 020	5 850	6 070	5 970	6 070	5 850	5 020	3 720	2 380
	10	1 400	2 020	3 240	4 550	5 520	5 950	5 940	5 950	5 520	4 550	3 240	2 020
September	0	900	1 230	2 200	3 520	4 820	5 760	6 130	5 760	4 820	3 520	2 200	1 230
	10	880	1 070	1 930	3 200	4 530	5 580	6 080	5 580	4 530	3 200	1 930	1 070
Oktober	0	510	530	1 010	2 110	3 570	4 960	5 620	4 960	3 570	2 110	1 010	530
	10	470	480	650	1 500	2 850	4 290	4 870	4 290	2 850	1 500	650	480
November	0	200	200	270	840	1 910	3 040	3 480	3 040	1 910	840	270	200
	10	160	160	160	300	990	1 590	1 810	1 590	990	300	160	160
December	0	80	80	90	350	1 060	1 770	2 030	1 770	1 060	350	90	80
	10	40	40	50	60	90	120	130	120	90	60	50	40

Refer to table 4, there are "0-value" and "10-value". This is because of the two different kinds of windows' position.

The following figure shows the way to distinguish the two types of window:

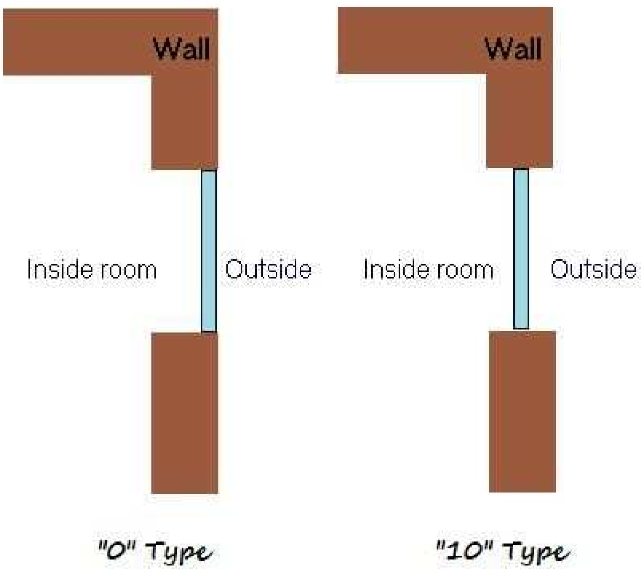


Figure 13: The two types of windows' position

In this case, all the windows in the building are "10" type, so we take the value from "10" group.

Table 5: The U-value coefficient and Calculation Factor

WINDOWS TYPE	U-VALUE	CALCULATION FACTOR
1-glass, normally	5.4	0.90
2-glass, normally	2.9 – 3.0	0.80
3-glass, normally	1.9 – 2.0	0.72
Special glass	1.0 – 1.5	0.69
2-glass, energy glass	1.0 – 1.5	0.70

In this building, all the windows are 2-glass normally. So refer to table 5, we take the calculation factor 0.80 to calculate.

From half May to half September, there is no heating demand cause the outdoor temperature is high. So it is unnecessary to calculate the solar radiation during this period.

Table 6: Solar radiation of North -150° face

N: -150°	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	70	31	467.87	0.8	812222.32
February	340	28			3563297.92
March	730	31			8470318.48
April	1640	30			18415363.2
Half May	2570	15			14429110.8
Half September	1070	15			6007450.8
October	480	31			5569524.48
November	160	30			1796620.8
December	40	31			464127.04
Total					**59528035.84**

Table 7: Solar radiation of East -60° face

E: -60°	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	140	31			996522.9
February	2240	28			14401364.8
March	3920	31			27902644.6
April	5420	30			37335171.3
Half May	5840	15	287.017	0.8	20114151.3
Half	4530	15			15602244.1
October	2850	31			20286361.5
November	990	30			6819523.8
December	90	31			640621.82
Total					**144098606.3**

Table 8: Solar radiation of South 30° face

S: 30°	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	180	31			2091026.88
February	3530	28			37038906.2
March	5290	31			61452956.6
April	6160	30			69251212.8
Half May	5920	15	468.42	0.8	33276556.8
Half	5580	15			31365403.2
October	4290	31			49836140.6
November	1590	30			17874907.2
December	120	31			1394017.92
Total					**303581128.3**

Table 9: Solar radiation of West 120° face

W: 120°	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	70	31			473441.92
February	400	28			2443571.2
March	1290	31			8724858.24
April	2810	30			18392236.8
Half May	3910	15	272.72	0.8	12796022.4
Half September	1930	15			6316195.2
October	650	31			4396246.4
November	160	30			1047244.8
December	50	31			338172.8
Total					**54927989.76**

So refer to the above four tables, and refer to [5], the total energy from solar radiation is 562135760.2Wh, that is, approximately 562MWh.

3.1.3 Free heat from people, lights, computer and all the equipments

Because the building is a resident building, it is impossible to count the accurate number of people and electricity equipments. So we just take the number of rooms into calculation.

$$Q_{Int} = Average\_energy\_emission * No\_room * No\_hours \qquad [6]$$

Table 10: Calculation of Internal Heating

	Apartments number	Average energy emission(W)	Number of hours(h)	Heat Loss (Wh)
1-room	32	200	5832	37324800
2-room	48	250		69984000
3-room	79	350		161254800
4-room	11	500		32076000
Special 2-room	10	250		14580000
Total				**315219600**

There is no district heating during summer, that is, from half May to half September, so we only calculate the hours except summer time. Then the number of hours is 5832h.

Refer to [6] and Table 10, the total free heat from internal of the building is 315MWh.

3.2 Heat Loss

3.2.1 Heat Loss in Transmission

The equation of transmission:

$$Q_{tran} = U * A * Q_{\deg ree} \qquad [7]$$

-U-value is different because the different material of the building

-A is the area of each part of building envelope (m^2)

U-value:

Table 11: U-value of building structure

	U-value
Wall	0.25
Door	1.00
Roof	0.17
Window, 2-glass	2.90
Window, 3-glass	1.90
Floor	0.30
Floor Basement	0.60
Wall Basement	0.80

Area:

A_{wall} = 5043 m^2 A_{window} = 1564.21 m^2

A_{door} = 619.65 m^2 A_{roof} = 3929.8 m^2

A_{floor1} = 3373.88 m^2 A_{floor2} = 555.8 m^2

$A_{basement\ wall}$ = 1021.83 m^2

The calculation process of Q_{degree}:

January: (21-(-2)) ℃ * 24 h/day * 31 day/month = 17112

February: (21-(-5.4)) ℃ * 24 h/day * 28 day/month = 17740.8

March: (21-2.8) ℃ * 24 h/day * 31 day/month = 13540.8

April: (21-7) ℃ * 24 h/day * 30 day/month = 10080

Half May: (21-9.6) ℃ * 24 h/day * 31 day/month = 4240.8

Half September: (21-10.5) ℃ * 24 h/day * 30 day/month = 3780

October: (21-6) ℃ * 24 h/day * 31 day/month = 11160

November: (21-0.5) ℃ * 24 h/day * 30 day/month = 14760

December: (21-(-0.2)) ℃ * 24 h/day * 31 day/month = 15772.8

$\therefore \sum Q_{degree}$ **= 108187.2 ℃ h**

Then we can get Q_{tran}:

Table 12: Heat Loss in Transmission

	Heat Loss in Transmission (MWH)
Wall	136
Window(2-glass)	491
Door	67
Roof	72
Wall(Basement)	88
Floor1	110
Floor2	18
Floor Basement 1	219
Floor Basement 2	36
Total	**1237**

Refer to [7] and Table 12, the heat loss in transmission is 1237 MWh.

3.2.2 Heat Loss in Ventilation:

The equation of ventilation:

$$Q_{ven} = V_{ven} * \rho * C_p * Q_{\deg ree} \qquad [8]$$

-ρ is the density of air (Kg/ m^3)

-Cp is the specific heat capacity of air (J/Kg.ºC)

As the following figure shows, there are totally five ventilation systems in the building. And we have measured the air flow data of each ventilation system.

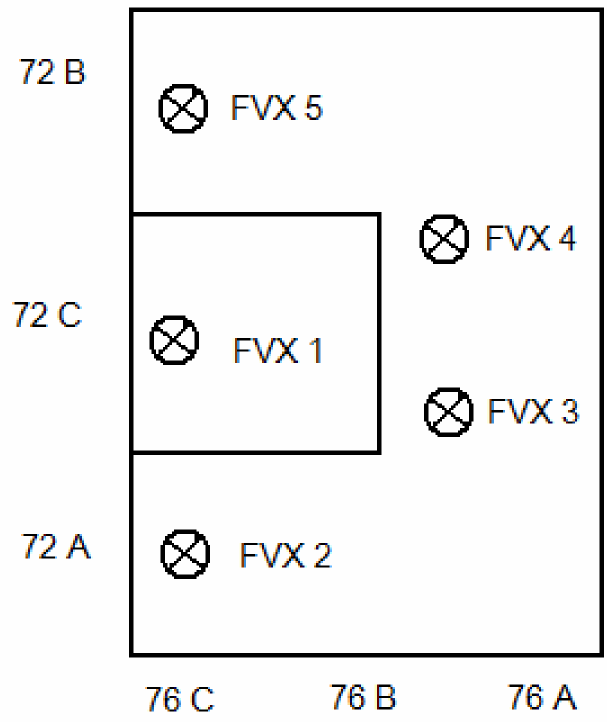


Figure 14: Location of ventilation systems in the building

After measurement of the air flow, we could calculate the heat loss in ventilation as following:

Table 13: Heat Loss in Ventilation

	V_{ven} (l/s)	Heat Loss in Ventilation(MWH)
FVX 1	1836	238
FVX 2	1852	240
FVX 3	1407	183
FVX 4	1417	184
FVX 5	1508	196
Total		**1041**

Refer to [8] and table 13, the total heat loss in ventilation is 1041 MWh.

3.2.3 Hot tap water

The equation of hot tap water:

$$Q_{water} = \rho * C_p * V * T \qquad [9]$$

- -ρ is the density of water (Kg/ m^3)
- -Cp is the specific heat capacity of water (J/Kg·ºC)
- -V is the amount of water that have been consumed (m^3)
- -T is the temperature difference(℃)

Table 14: Energy consumption data of year 2007

Year 2007				
Energi for heating	1265,700 MWh			
Heatpump-produktion	793,000 MWh			
Heatpump-electriciti	238,855 MWh (estimated)			
Electriciti for the building (not apartment)	706,305 MWh			
Waterconsumptions			15000	m3
Heatwater: Count with 38% of totalwater	38%		5700	m3
"Graddagar" 2007	3723			
"Normalår"	4131			

Refer to table 14, the hot tap water consumption in 2007 is 5700m^3.

Normally the cold water is 5 ºC and needed to be heated till 55 ºC. So the temperature difference for tap hot water is 50 ºC. Then refer to [9], Q_{water} can be gained:

Q_{water} = (1000 Kg/ m^3 * 4.19 J/Kg·ºC * 5700 m^3 * 50 ºC) / 3.6s ≈ 332MWh

3.2.4 Infiltration (Natural)

Natural infiltration refers to the normal air exchange between outdoor and indoor through natural way, such as the opened windows, the fans in the kitchen, and the cracks on the building envelope.

So the only way to calculate heat loss in this part is making use of energy balance.

The equation of energy balance is:

$$Q_{tran} + Q_{ven(Mech)} + Q_{ven(Natr)} + Q_{water} = Q_{DH} + Q_{solar} + Q_{Int} + Q_{pump} \quad [10]$$

All the parameters have been found out except the heat loss of natural ventilation, so refer to [10], it is easy to find that the value of $Q_{ven(Natural)}$ is 325.7MWh.

3.3 Energy Balance

After the analysis, the energy balance of this building can be shown as the following figure:

Table15: Energy Balance

Heat Loss (MWh)		Heat In (MWh)	
Transmission	1237	**DH**	1265.7
Hot tap water	332	**Heat Pump**	793
Mechanical	1041	**Solar Radiation**	562
Natural Ventilation	325.7	**Internal Heating**	315
2935.7		**2935.7**	

The heat loss and heat in of this building have run into equilibrium. For a clearer expression, the energy balance is shown as the chart:

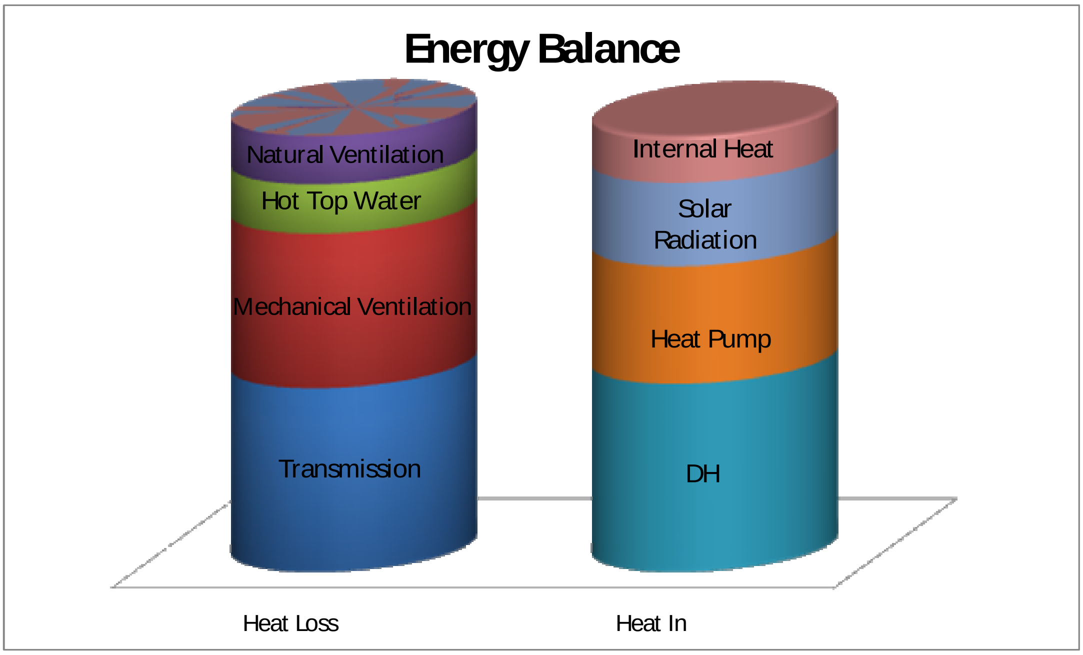


Figure 15: Chart of Energy Balance

4 Solutions

4.1 Discussion for energy saving

The building must obtain the energy to maintain the indoor temperature in the winter. The heat in of the building includes the district heating, heat pump and free heat from people, electrical equipments as well as solar radiation which enters through the windows, doors, roof and walls.

The heat loss of the building includes the heat loss in transmission through windows, doors, roof and walls, the heat loss in infiltration and hot tap water. Once the total heat in and heat loss is in equilibrium, the temperature keeps in constant.

Under such an Energy Balance, the most direct way to reduce total energy consumption is to reduce the heat loss. To find out the main problems of this building, the following charts are drawn to make the energy situation clearer to analyse:

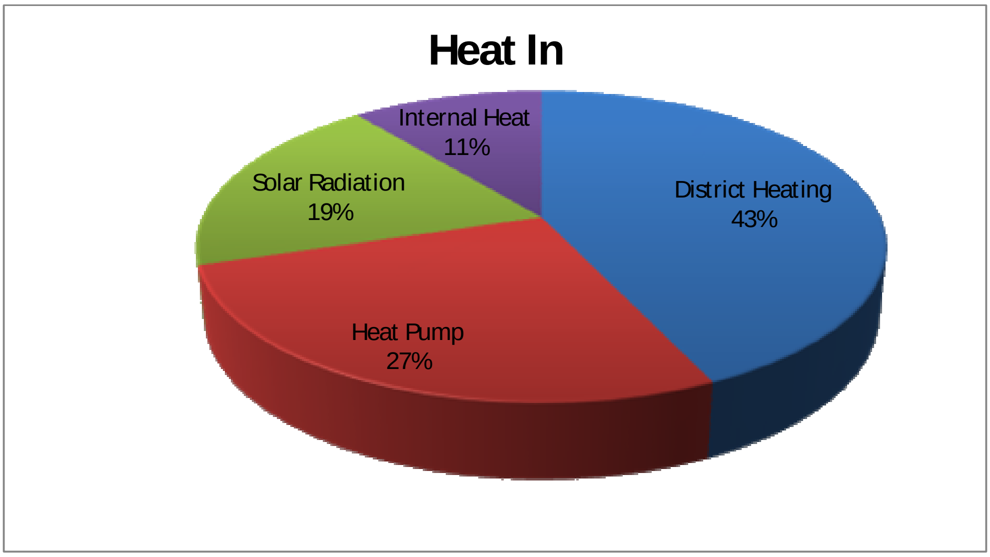


Figure 16: Energy Distribution of Heat In

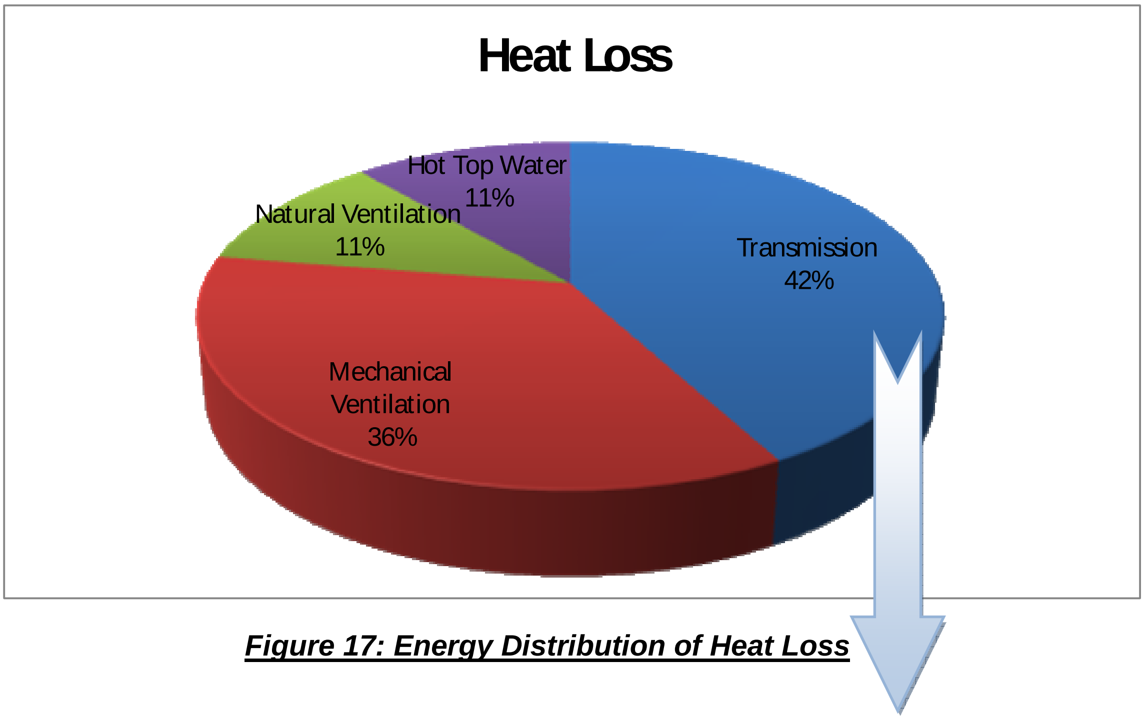


Figure 17: Energy Distribution of Heat Loss

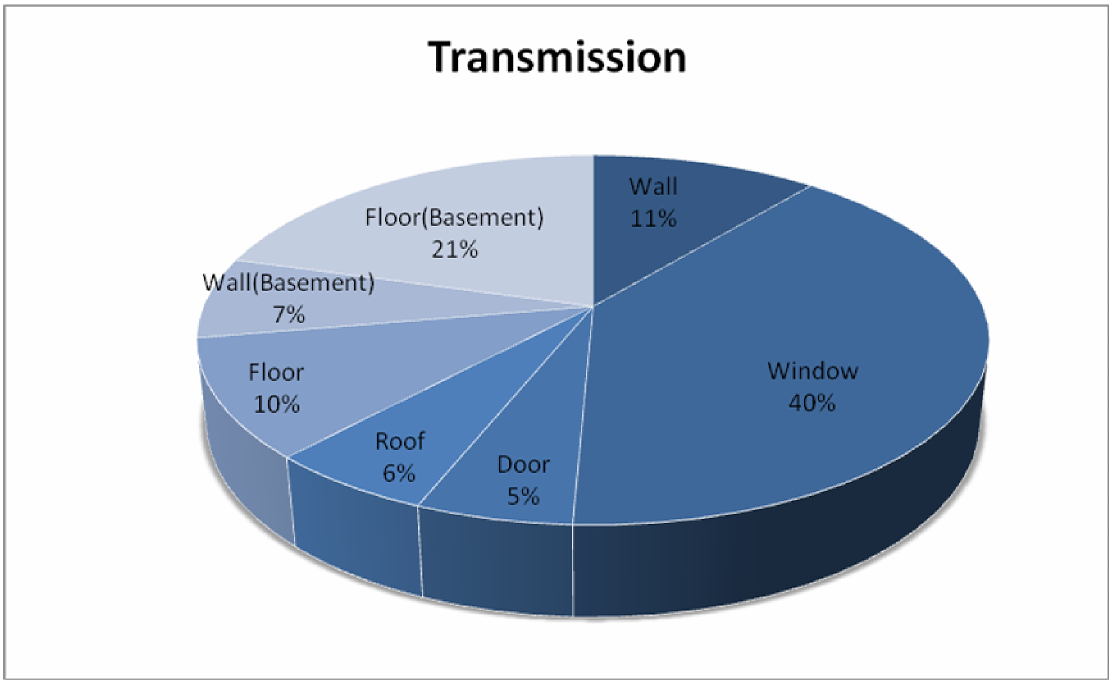


Figure 18: Energy Distribution of Transmission

From the above two charts, it can be seen that the transmission through the building envelope and the mechanical ventilation contribute most to heat loss. Among the parameters of transmission, the heat loss through the windows occupies the largest part.

So it is clear that we should pay more attention to transmission, especially the heat loss through windows, while doing the energy save analysis.

4.2 Use LOW-E membrane on the windows

The heat of solar radiation enters through the low emissive membrane (LOW-E membrane), at the same time 90% of long-wave infrared(remote infrared ray) which radiate by the indoor original heat sources(such as heating equipments) is reflected back to indoor by LOW－E membrane.

Superficial emissivity of the ordinary glasses is around 0.84, while the superficial emissivity of Low-e glass layer is below 0.33.In the winter, the most thermal radiation which is emitted from the inside heating and inside objects is reflected into indoor. And this guarantees that the indoor quantity of heat will not emit to outdoor, so that payment for heating will be saved. In the summer, the Low-e glass layer stops the thermal radiation which emitted from the outdoor ground and buildings' entering; therefore, the payment of air conditioner has been saved. The windows of this building is 2-glass window, so the U-value will be reduced to 1.8 from 2.9

The LOW-E membrane could use the outdoor short-wave solar radiation and the indoor long-wave radiation energy in full, so it could be very important to keep warm and save energy for the buildings in cold area.

The advantages of the LOW-E membrane are listed:

(1) More economical. It is much cheaper than changing all the windows into the heat reflection ones.

(2) More convenient.

(3) Environmental protection. Replacing glasses will produce massive construction trash of glass fragments and increase the cost of transportation and landfill. However, the LOW-E membrane could use the old glasses and promote the performance of heat insulation and the safety.

(4) Safer. The heat insulation membrane generally has the function of enhancing the safety, and simultaneously plays the role of sticking and holding the glasses fragment.

(5) Healthier. The membrane includes UV (ultraviolet ray) absorbent, which may cut off 98%-99%ultraviolet rays.

After adjustment, the U-value of windows will change from 2.9 to 1.8, so the heat loss due to transmission through windows would be:

$$Q_{window} = U_{window} * A_{window} * Q_{\deg ree} \qquad [11]$$

$$= 1.8 * 1564.21\text{m}^2 * 108187.2 \text{ ℃ h}$$

$$= 304609500\text{Wh} = 305\text{MWh}$$

So refer to [11], the reduction is 186MWh.

But considering the solar radiation, there would be some heat compensation. That is:

562*(0.72/0.80) = 506

562-506=56

186-56=130

Table16: Energy Saving on Transmission

	Before (MWh)	After (MWh)	**Reduction (MWh)**
Transmission	491	361	**130**

4.3 Lower the temperature of hot tap water

In this building, the tap water is heated by the district heating. The cold water is initially 5 ºC and heated till 55 ºC and then the hot tap water would be used mainly in the kitchens and in the toilets.

As mentioned above, the equation of hot tap water is:

$$Q_{water} = \rho * C_p * V * T \qquad [12]$$

Here, the density of water (ρ) and the specific heat capacity of water (C_p) are constant thus impossible to change. The amount of consumed water mainly depends on the people who have activities in the building, so it is out of control. The only way and best way to reduce the heat loss of hot tap water is to decrease the temperature difference (T).

Recommended hot water temperature is between 49 ºC and 60 ºC. A temperature lower than 49 ºC can lead to the growth of the bacteria that causes Legionnaires' disease, and a temperature higher than 60 ºC would easily cause scalds.

So if the highest temperature could be altered from 55 ºC into 50ºC, while keeping the good balance between the need to control Bacteria and hot tap water safety, the heat loss of hot tap water can be reduced.

Refer to [12], after adjustment, the heat loss of hot tap water is:

$$Q_{water} = (1000\ Kg/m^3 * 4.19\ J/Kg\cdot{}^oC * 5700\ m^3 * 45\ {}^oC) / 3.6s$$

$$= 298{,}537{,}500Wh \approx 299MWh$$

Table 17: Energy Saving on Hot tap water

	Before (MWh)	After (MWh)	**Reduction (MWh)**
Hot tap water	332	299	**33**

4.4 Optimize lighting Systems-Use Compact fluorescent lamp

The lighting system is essential in activities in the modern city. Use the energy conservation lighting system is very important to reduce the resources waste. Therefore, it is necessary to use more and more energy conservation lighting systems for increasing the energy efficiency.

Most principles of the compact fluorescent lamp and the ordinary fluorescent lamp are almost the same. But the tiny difference between them is that the compact fluorescent lamp connects the fluorescent with the ballast (electromagnetic or electronic).

The compact fluorescent lamp has many kinds of models and sizes, and can be applied wherever the ordinary incandescent lamp is applied. The luminous efficiency of a compact fluorescent lamp is approximately 4 times of the ordinary lamp. What's more, compared with an incandescent lamp, the working life of fluorescent lamp is more than 16 times. The following picture shows different kinds of compact fluorescent lamps:

Figure 19: Different shapes and sizes of compact fluorescent lamp

The compact fluorescent lamp usually has around 8,000 hours of working life, however the incandescent lamp has only 500-2000 hours. At the same time the power consumption is only 25% of the incandescent lamp's. For example, the illuminating effect of a 22W compact fluorescent lamp is equal to a 100W incandescent lamp.

Once the compact fluorescent lamp use the electronic ballast, the energy conservation effect will be much better. Because the electronic ballast has high frequency operation, using the ballast is able to increasing the luminous efficiency of compact fluorescent lamp further.

With the same luminous efficiency, the difference of energy consumption between the compact fluorescent lamp and incandescent lamp is shown as following:

Table 18: Comparison of different lamps

Same Luminous Efficiency	
Compact fluorescent lamp	**Incandescent Lamp**
8 -10 W	40 W
11-15 W	60 W
18-20 W	75 W
20-25 W	100W

5. Conclusion

5.1 Energy survey of the building

The aim of this paper is to make a detailed analysis of the current energy situation of the building, then evaluate a series of ways to reduce the energy consumption and optimize the energy efficiency.

This building is a residential building. It lies in the south of Gavle, just at the crossing of S. Centralgatan and Nedre Åkargatan street. There are 180 apartments in this building in total.

During the energy survey and save progress, first the whole condition of energy balance of this building is analyzed. There are several parameters that involve the heat loss and heat in of whole building, so each parameter in the energy balance equation is extracted and calculated. Then it can be seen that the transmission occupy most of the heat loss part, so this parameter should be given higher consideration while doing the energy save analysis. The simulation program has been used during the progress. After a plenty of inquisition into the energy situation, we suggested several solutions to save energy as well as cost for this building.

5.2 Solutions and results

5.2.1 Solutions

The windows have been used for several years without changing. The windows of this building are the 2-glass windows whose U-value is 2.9 and a large amount of heat transmits through this type of windows.

Table 19: Energy Saving on Transmission

	Before(MWh)	After(MWh)	**Reduction(MWh)**
Transmission	491	361	**130**

Refer to table 18, after using the Low-E Membrane, the transmission heat loss has been reduced 361MWh.

The hot tap water also contributes a lot to heat loss. Because the only parameter which can influence the heat loss of hot tap water is the temperature difference of cold water and hot water, so the solution is to reduce the highest temperature from 55 ºC to 50 ºC.

Table 19: Energy Saving on Hot tap water

	Before(MWh)	After(MWh)	**Reduction(MWh)**
Hot tap water	332	299	**33**

Refer to table 19, after reducing the temperature, the heat loss of hot tap water has been reduced 33MWh.

5.2.2 Results

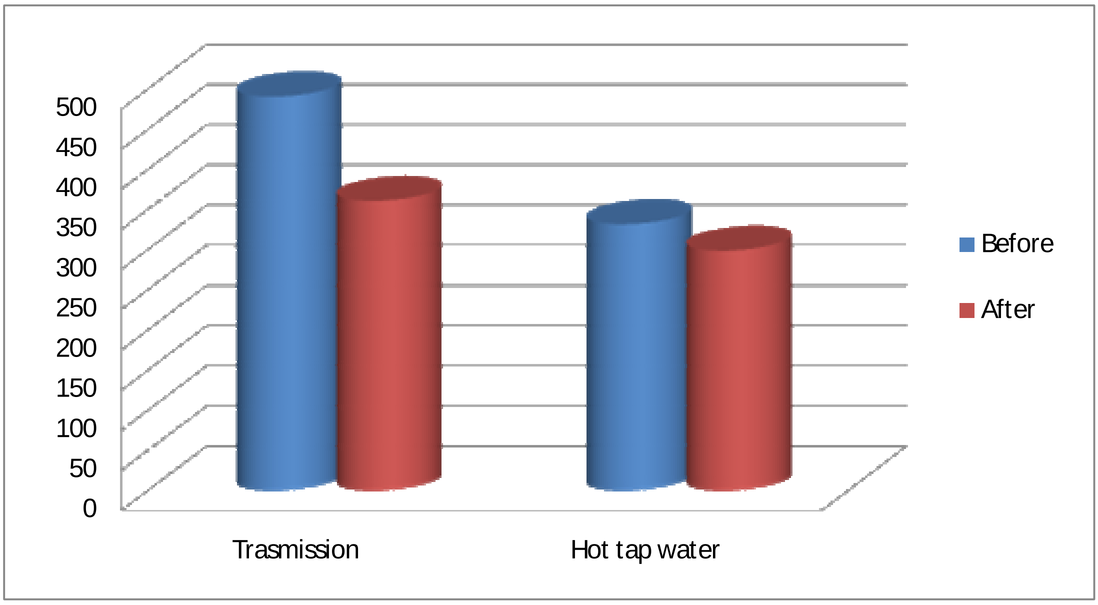


Figure 20: Results of each parameter

Refer to Figure 20, the total reduction of heat loss after adjustment is 163MWh, accounts 5.6% of originally heat loss. The heat loss of the building has been reduced from 2935.7MWh to 2772.7MWh.

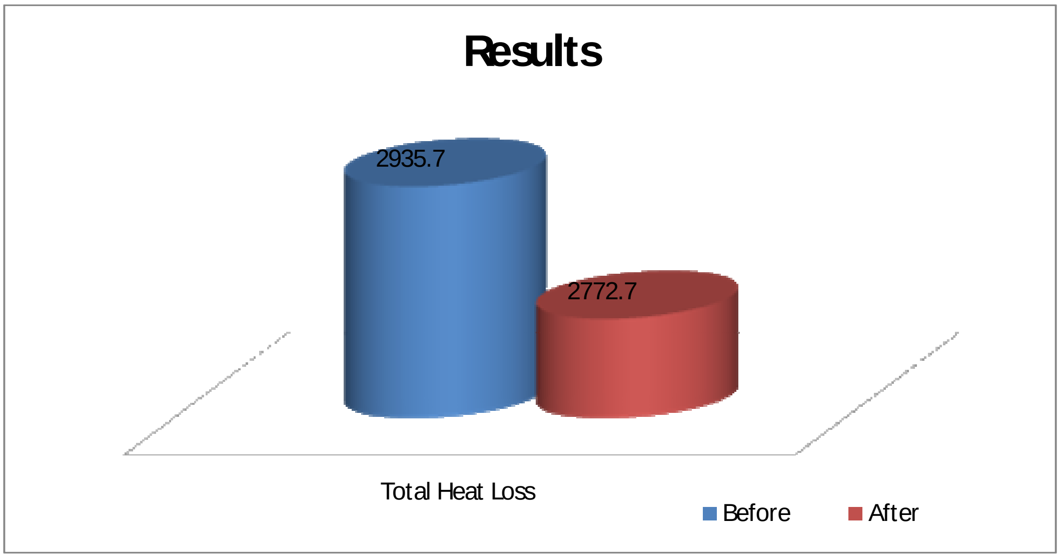


Figure 21: Results of total Energy Saving

Reference:

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Heimo Zinko, Literature and slides of the course in *Energy Systems, District* *heating lecture,* Högskolan i Gävle, , 2007

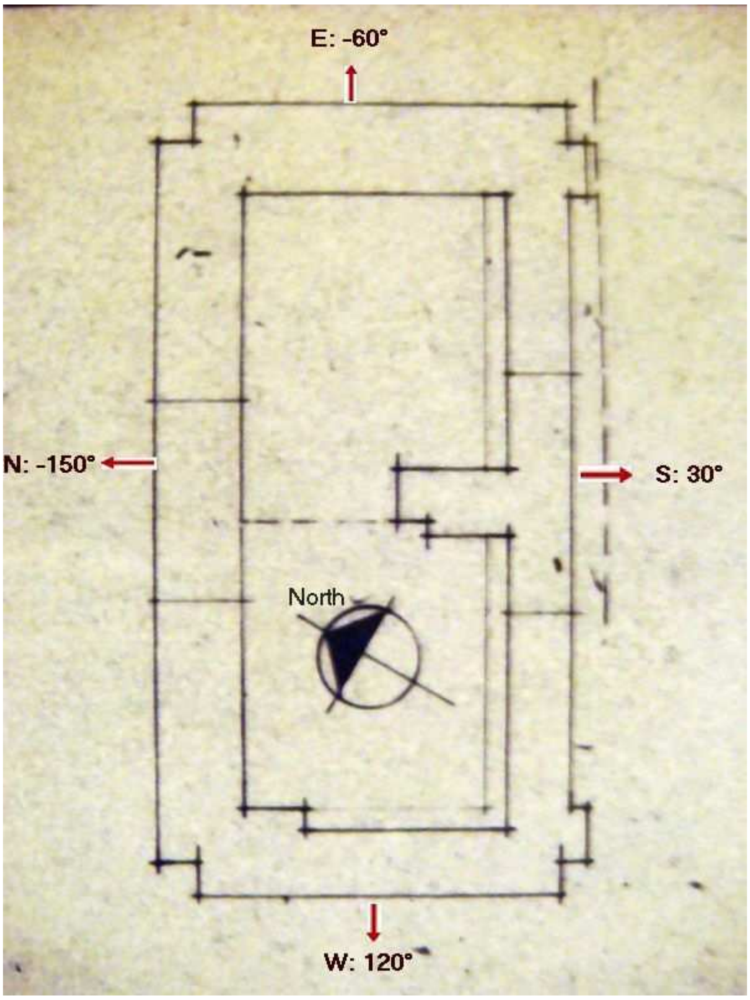
Appendix:

1. The energy consumption bill of the building:

Year 2007			
Energi for heating	1265,700 MWh		
Heatpump-produktion	793,000 MWh		
Heatpump-electriciti	238,855 MWh (estimated)		
Electriciti for the building (not apartment)	706,305 MWh		
Waterconsumptions		15000	m3
Heatwater: Count with 38% of totalwater	38%	5700	m3
"Graddagar" 2007	3723		
"Normalår"	4131		

2. Solar radiation:

This is the direction of the building:



This is the value of Wh/m^2 for each angle of the building:

Månad	Horisont-avskärmning,°	Vertikala ytans oriemering N			E			S			W		
		−180	−150	−120	−90	−60	−30	0	30	60	90	120	150
Latitud 60 °N													
Januari	0	130	130	160	550	1440	2360	2710	2360	1440	550	160	130
	10	70	70	70	90	140	180	200	180	140	90	70	70
Februari	0	370	370	640	1550	2900	4280	4880	4280	2900	1550	640	370
	10	340	340	400	1030	2240	3530	4020	3530	2240	1030	400	340
Mars	0	730	900	1720	3050	4520	5740	6320	5740	4520	3050	1720	900
	10	710	730	1290	2460	3920	5290	5970	5290	3920	2460	1290	730
April	0	1350	1990	3320	4750	5850	6370	6410	6370	5850	4750	3320	1990
	10	1170	1640	2810	4220	5420	6160	6390	6160	5420	4220	2810	1640
Maj	0	2350	3050	4460	5630	6150	5980	5730	5980	6150	5630	4460	3050
	10	1840	2570	3910	5130	5840	5920	5710	5920	5840	5130	3910	2570
Juni	0	3210	3870	5230	6190	6350	5820	5460	5820	6350	6190	5230	3870
	10	2420	3180	4570	5650	6070	5790	5430	5790	6070	5650	4570	3180
Juli	0	2830	3510	4910	5960	6280	5820	5580	5890	6280	5960	4910	3510
	10	2270	3020	4410	5540	6050	5870	5560	5870	6050	5540	4410	3020
Augusti	0	1700	2380	3720	5020	5850	6070	5970	6070	5850	5020	3720	2380
	10	1400	2020	3240	4550	5520	5950	5940	5950	5520	4550	3240	2020
September	0	900	1230	2200	3520	4820	5760	6130	5760	4820	3520	2200	1230
	10	880	1070	1930	3200	4530	5580	6080	5580	4530	3200	1930	1070
Oktober	0	510	530	1010	2110	3570	4960	5620	4960	3570	2110	1010	530
	10	470	480	650	1500	2850	4290	4870	4290	2850	1500	650	480
November	0	200	200	270	840	1910	3040	3480	3040	1910	840	270	200
	10	160	160	160	300	990	1590	1810	1590	990	300	160	160
December	0	80	80	90	350	1060	1770	2030	1770	1060	350	90	80
	10	40	40	50	60	90	120	130	120	90	60	50	40

This is the U-value coefficient and Calculation Factor of the windows in the building:

WINDOWS TYPE	U-VALUE	CALCULATION FACTOR
1-glass, normally	5.4	0.90
2-glass, normally	2.9 – 3.0	0.80
3-glass, normally	1.9 – 2.0	0.72
Special glass	1.0 – 1.5	0.69
2-glass, energy glass	1.0 – 1.5	0.70

Then the calculation progress of the solar radiation is shown as following charts:

N: -150°

	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	70	31	467.87	0.8	812222.32
February	340	28			3563297.92
March	730	31			8470318.48
April	1640	30			18415363.2
Half May	2570	15			14429110.8
Half September	1070	15			6007450.8
October	480	31			5569524.48
November	160	30			1796620.8
December	40	31			464127.04
Total					**59528035.84**

E: -60°

	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	140	31	287.017	0.8	996522.9
February	2240	28			14401364.8
March	3920	31			27902644.6
April	5420	30			37335171.3
Half May	5840	15			20114151.3
Half September	4530	15			15602244.1
October	2850	31			20286361.5
November	990	30			6819523.8
December	90	31			640621.82
Total					**144098606.3**

S: 30°

	Value of	Days of	Area of	U-value	Solar

	(Wh/m²)	each month	Windows (m²)	coefficient	Radiation (Wh)
January	180	31			2091026.88
February	3530	28			37038906.2
March	5290	31			61452956.6
April	6160	30			69251212.8
Half May	5920	15	468.42	0.8	33276556.8
Half September	5580	15			31365403.2
October	4290	31			49836140.6
November	1590	30			17874907.2
December	120	31			1394017.92
Total					**303581128.3**

W: 120°

	Value of (Wh/m²)	Days of each month	Area of Windows (m²)	U-value coefficient	Solar Radiation (Wh)
January	70	31			473441.92
February	400	28			2443571.2
March	1290	31			8724858.24
April	2810	30			18392236.8
Half May	3910	15	272.72	0.8	12796022.4
Half September	1930	15			6316195.2
October	650	31			4396246.4
November	160	30			1047244.8
December	50	31			338172.8
Total					**54927989.76**

3. Internal Heating:

The number of rooms and the average energy emission of each type of room as well as the calculation of Internal Heating is:

	Apartments number	Average energy emission(W)	Number of hours(h)	Heat In (Wh)
1-room	32	200	5832	37324800
2-room	48	250		69984000
3-room	79	350		161254800
4-room	11	500		32076000
Special 2-room	10	250		14580000
Total				**315219600**

4. Transmission:

The U-value of all the materials of the building structure is:

	U-value
Wall	0.25
Door	1.00
Roof	0.17
Window, 2-glass	2.90
Window, 3-glass	1.90
Floor	0.30
Floor Basement	0.60
Wall Basement	0.80

The calculation process of Q_{degree}:

January: (21-(-2)) ℃ * 24 h/day * 31 day/month = 17112

February: (21-(-5.4)) ℃ * 24 h/day * 28 day/month = 17740.8

March: (21-2.8) ℃ * 24 h/day * 31 day/month = 13540.8

April: (21-7) ℃ * 24 h/day * 30 day/month = 10080

Half May: (21-9.6) ℃ * 24 h/day * 31 day/month = 4240.8

Half September: (21-10.5) ℃ * 24 h/day * 30 day/month = 3780

October: (21-6) ℃ * 24 h/day * 31 day/month = 11160

November: (21-0.5) ℃ * 24 h/day * 30 day/month = 14760

December: (21-(-0.2)) ℃ * 24 h/day * 31 day/month = 15772.8

∴ $\sum Q_{degree}$ = 108187.2 ℃ h

5. Ventilation:

The location of ventilation systems in the building: