LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY

LUT School of Energy Systems

Triple Degree Program in Energy Technology

Gaurav Bhati

Energy modeling of Industrial or commercial buildings

Supervisor
Associate Professor Tero Tynjala
PhD student Eero Inkeri

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Gaurav Bhati

Abstract

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Energy modeling of Industrial or commercial buildings
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Examiner: Associate Professor Tero Tynjala
Instructor: M.Sc. Eero Inkeri

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The main motive of the thesis is to study the energy consumption of any building with advanced energy solutions. We started from the basics i.e. by creating a general model of a building, in this case, it is a student apartment. This model shows the replica of a real building located in Garbsen, Germany. The ultimate aim is to make it a near-zero energy building. There are some other things which we need to consider like CO2 emissions and technical solutions to make it net-zero or nearly zero.

The simulation work is performed with IDA ICE (v4.8). This software provides a lot of flexibility to customize building and possibility for input and to determine and investigate important parameters, variables, and values.

The simulation is done by making replica models. There are few changes in the model so that there is improvement in different losses and energy conservation. The real building does not have any renewable energy source. It gets all its energy from the grid. The model developed by IDA ICE has a wind turbine, solar panels for electricity and thermal, heat pumps. A wind turbine with a capacity of 10kW has been installed along with solar panels with a surface area of 4000 m^2. In this work, two models with different envelop properties have been compared to show the variation causes due to

heat transfer coefficient. The simulation takes nearly 4-5 hours to complete after all required and mandatory inputs. The result has a significant difference from model1 to model2. Model 1 fulfills only 58.88 of building energy demand and on the other hand, model2 fulfills around 70.67% of building energy demand. Although in model 2 materials with high-end properties have been used and therefore are going to be more costly. The use of model2 produces a significant amount of energy but not enough that we can say that it is a net-zero energy building. Although if we further add some minor but significant technologies then we can save a considerable amount of energy and then the energy required by the building is going to be less. The emission by the powerplants can be reduced in this way but then we need to consider the emission associated with these renewable technologies.

Contents

Symbols

A	Surface area	[m^2]
C_p	specific heat	[J/kgK]
g	solar factor	
L	length of thermal bridge	[m]
m	mass flow rate	[kg/s]
P	pressure drop through ventilator	[Pa]
Q	heat flow rate	[W]
q	specific heat flux	[W/m2]
R	Overall thermal resistance	[m^2 K / W]
t	time	[s]
T	temperature	[^{o}C]
U	Heat transfer coefficient	[W/m^2 K]
V	air volume flow rate	[m^3/s]
α	Heat transfer coefficient	[W/m^2 K]
δ	Wall thickness	[m]
H	Efficiency	
λ	thermal conductivity coefficient	
Ψ	linear thermal transmittance of the thermal bridge	[W/mK]

Subscripts

f	reduction factor for heavy buildings
$\boldsymbol{i}$	internal
m_i	mass flow rate of infiltration air
o	outer

sol	solar radiation
v	ventilation

Abbreviation:

CO2	Carbon dioxide
EU	European Union
GtCO2	Giga tonnes of Carbon dioxide
Mtoe	Millions of tonnes of oil equivalent
NDC	Nationally Determined Contributions
OECD	Organisation for Economic Co-Operation
SDS	Sustainable Development Scenario
TES	Total Energy Supply

1 Introduction

The energy demand is nothing new. Initially, when there were advancements in technology the consumption of energy increased rapidly. This demand for Energy has to be fulfilled by any means so humans used a lot of resources to produce energy. They did not think of the consequences which lead to various natural destructions. I would like to show energy consumption in buildings around the world. The energy can be in the form of electricity, heating, cooling, warm water, and lighting. New technologies are employing which we can reduce the consumption of energy in buildings. This increasing energy demand needs to be fulfilled so there comes into account renewable energy resources. But out of all the sectors the building and infrastructure sector consumes the most amount of the energy produced around the world. So, we discussed one aspect that we produce more energy but there is also another aspect to the scenario, and these are that we should use energy more efficiently by improving our daily habits and by using energy-efficient instruments and types of equipment, second is that to improve our building infrastructure. In both cases, energy consumption can be reduced.

The demand for energy in a building is based on three major factors, i.e. people, technology, and outdoor climate. People somehow affect technological factors and use, which leads to different energy needs. Outdoor climate includes wind, location of building, sun, and temperature.

1.1 Aim

The thesis aims to create an energy model of a building then to provide detailed input such as heating types of equipment, lighting, building envelope, and so on. With the created model, finding out the energy consumption of the building in terms of heating, cooling, warm water, electricity, lighting, and so on. Further in this work, different renewable technologies have been used to make building nearly zero energy building.

2 Statistics

Specifically, around 35% of the final energy is consumed in homes. It includes all sectors such as electricity, heating, gas.

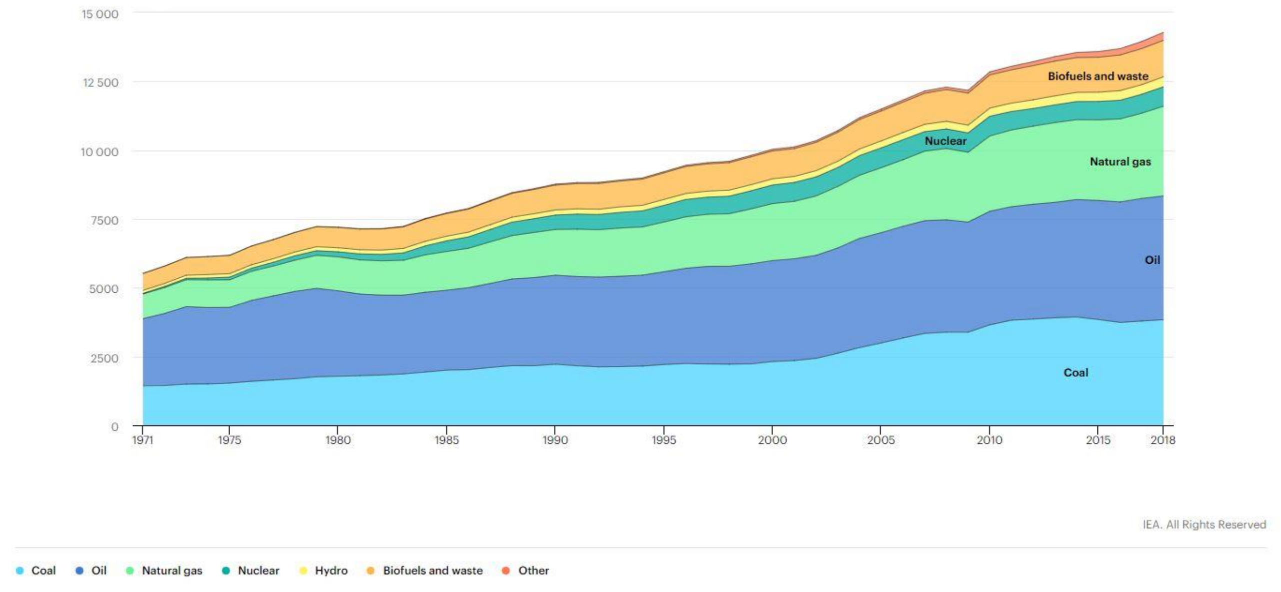


Figure 1: Total primary energy supply by source, world 1971-2018.[1]

It can be seen from figure 1 that the contribution of renewable till 2016 is nearly negligible. This means the changes took place only in recent years.

Energy production around the world was 14.421 Mtoe in 2018 and if we compare it to 2017 that it has increased 3.2%. And the fuels used to produce that energy are fossil fuels like natural gas, coal, and oil. Fossil fuels account for around 81% of production in 2018 as compared to 2017.

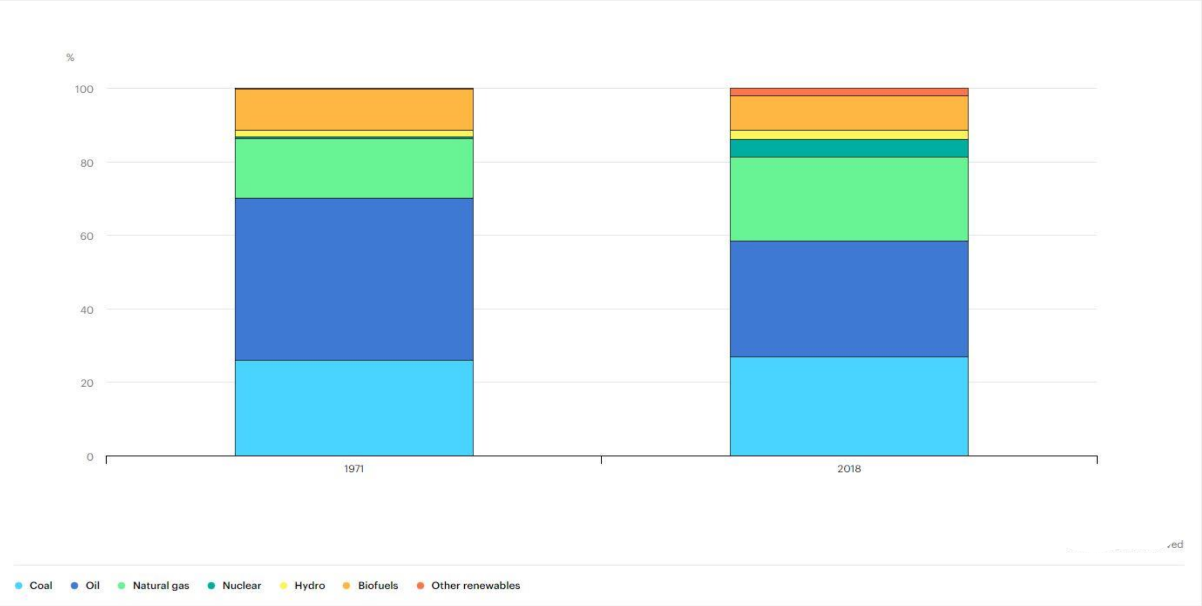


Figure 2: Total primary energy supply by fuel, 1971 and 2018.[28]

Figure 2 shows that TES in OECD dropped from 61% in 1971 to 38% in 2018. And in non-OECD Asia, the energy demand grew and reached 5136 Mtoe in 2018 and the share of TES has increased from 13% in 1971 to 36% in 2018.

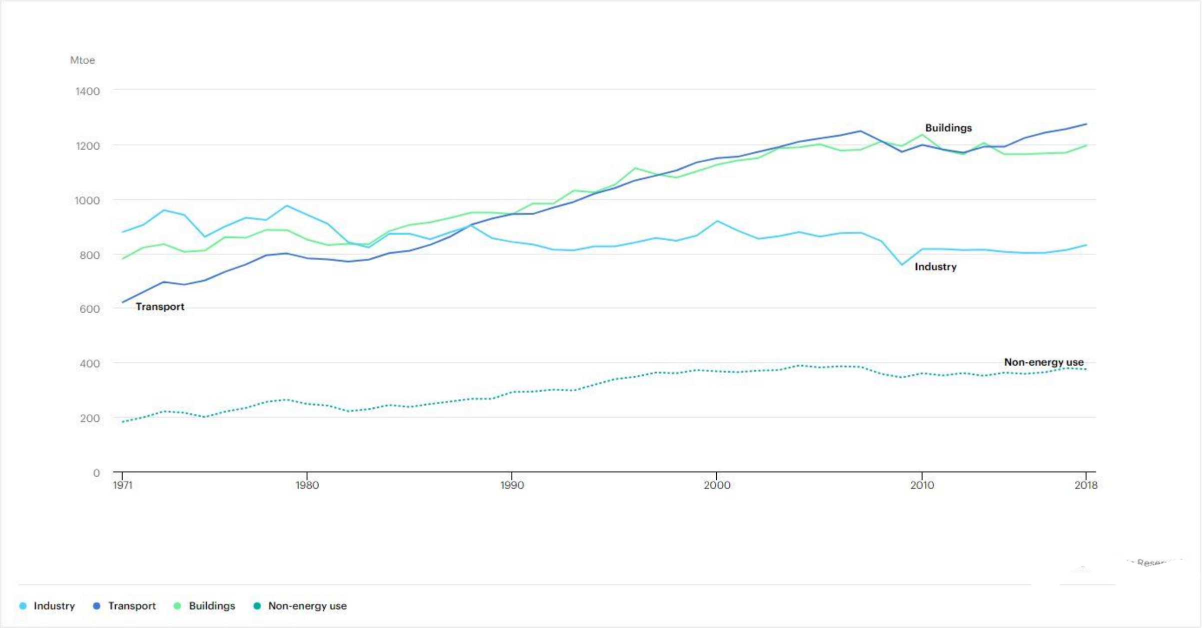


Figure 3: Total final consumption by sector, OECD, 1971-2018.[29]

The energy consumption in the transport sector is increasing rapidly and as per the stats shown in figure 3, it is going to keep its position on the top. Buildings also show an increase in consumption.

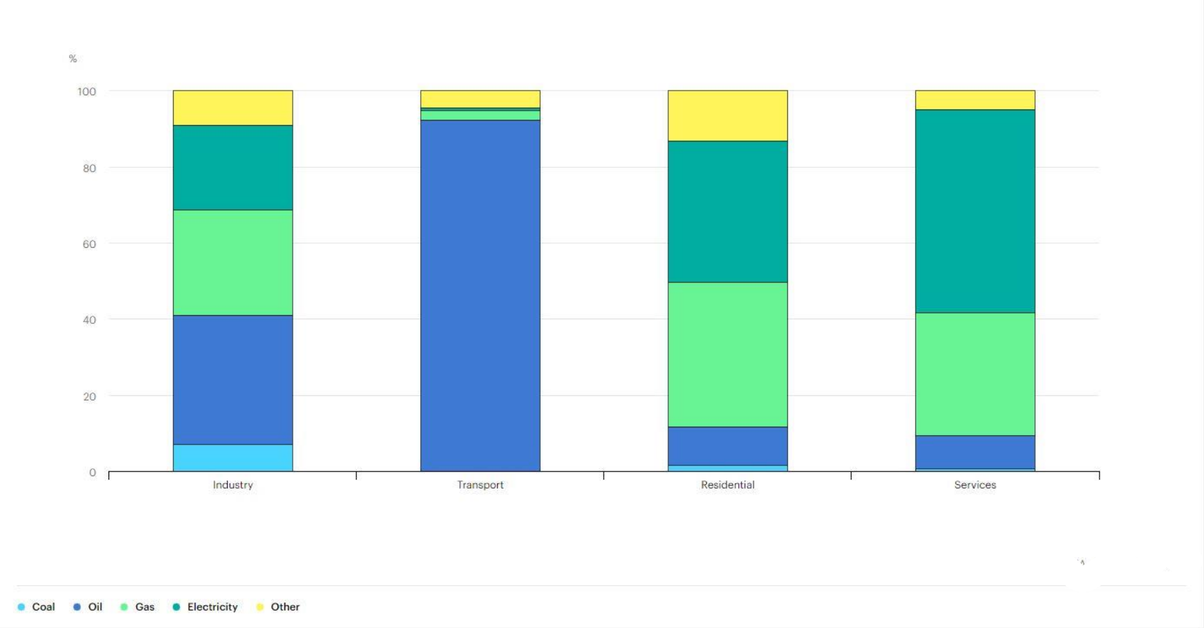


Figure 4: Final consumption by sector and source, OECD, 2018.[30]

In the transport sector, the consumption of oil is around 92%. figure 4 shows that residence has significant consumption of gas and coal.

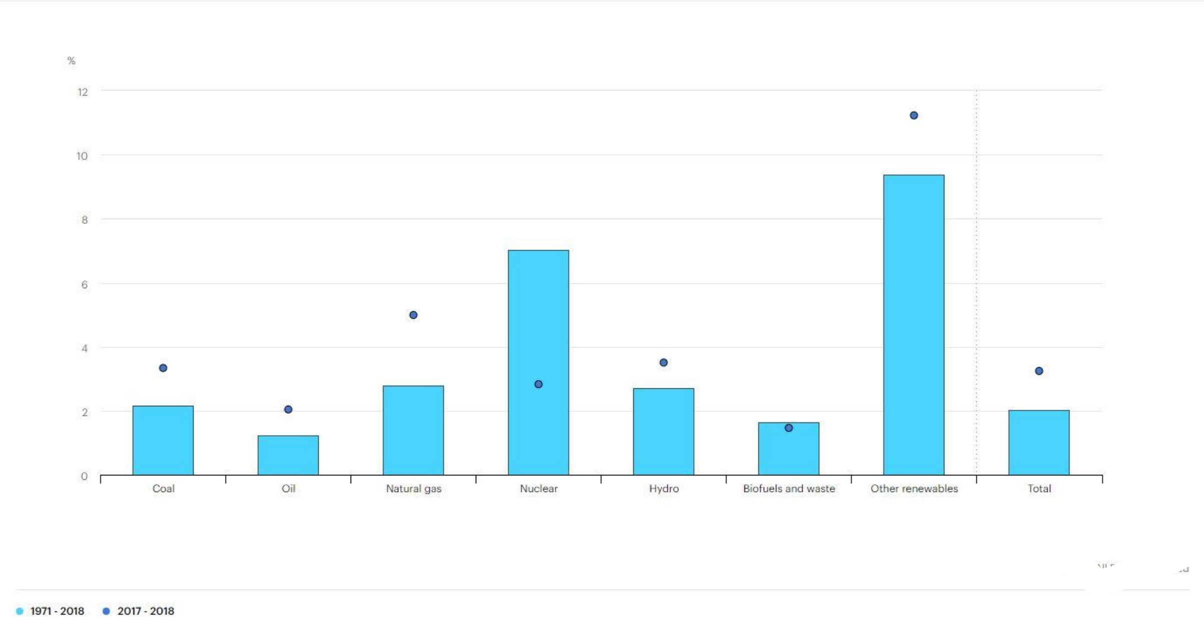


Figure 5: Global annual average change in energy production by fuel type from 1971-2018.[31]

The production of energy in OECD has increased by 200 Mtoe from 2017 to 2018. And figure 5 shows that non-OECD Asia has increased by 4%. The Middle East is the third-largest producing region.

The production and consumption of energy lead to the production of various gases and one of them which is very important is carbon dioxide. Here we will discuss the CO_2 production based on different factors and also the contribution of the big economies.

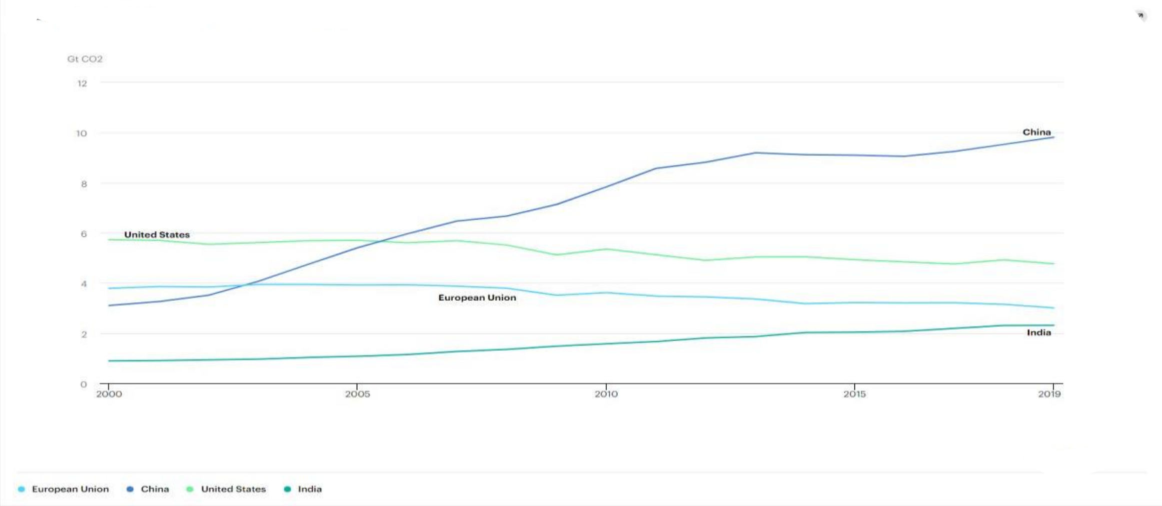


Figure 6: The amount of CO_2 emission from fuel combustion in some economies, 2000-19 [32]

In 2018, the CO_2 emission from fuel combustion around the world reached 33.5 GtCO2. But in 2019 there was a slight decline of 1% in CO_2 emission. India and China are some of the growing economies which emit a large amount of CO_2 in the atmosphere. USA, Japan, EU has shown negative CO_2 emission in last few years because of various environmental policies.

If we look at the CO_2 emission, by sector then we can notice that electricity and heat, industry, buildings, and transport are some of the largest global emitting sectors in 2018.

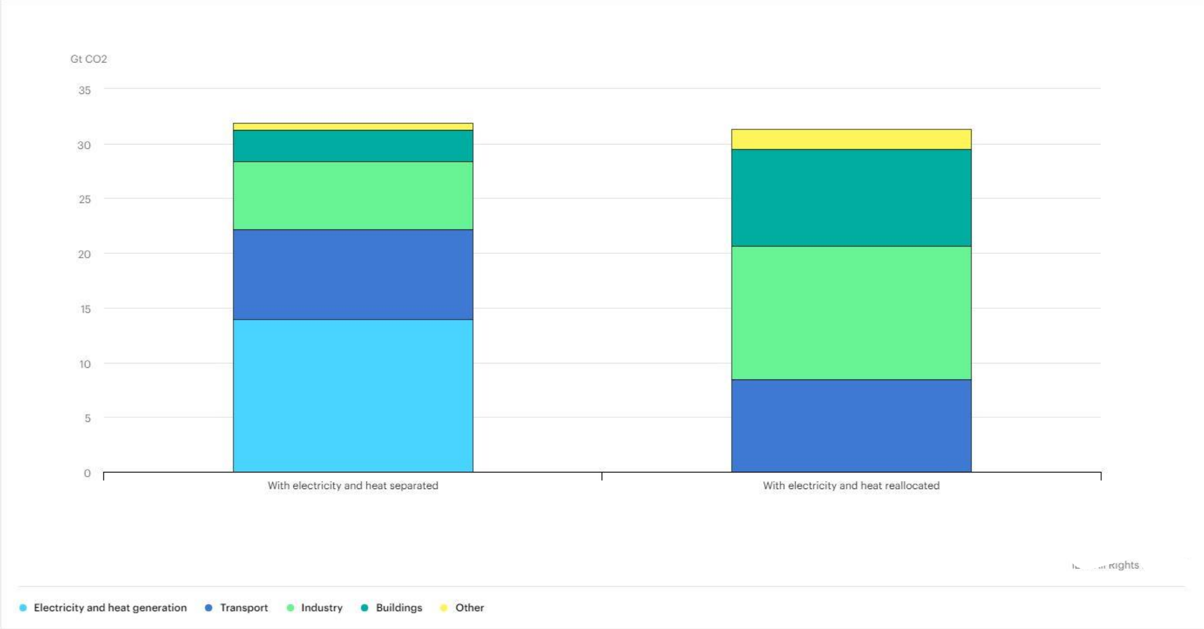


Figure 7: CO2 emission by Sector.[33]

Till now we have discussed energy production, consumption, use in the sector, emissions related.

Now we are discussing energy use in Buildings.

One-third of global energy consumption is consumed by buildings and the construction sector combined and is responsible for 36% of CO_2 emission [3] directly or indirectly.

In recent years CO_2 emissions from buildings raised rapidly. Only in 2019, there were 10 $GtCO_2$ of direct and indirect emissions from electricity and commercial heat used in buildings. It is the highest ever recorded.

To achieve the Sustainable Development Scenario there should be 2.5% of the annual global drop in energy intensity per m^2.

This target can only be achieved by 2030 with some strong building policies and codes, building renovation, by introducing the technologies like heat pumps (50% improvement in the average performance of cooling units), and taking other energy efficiency measures.

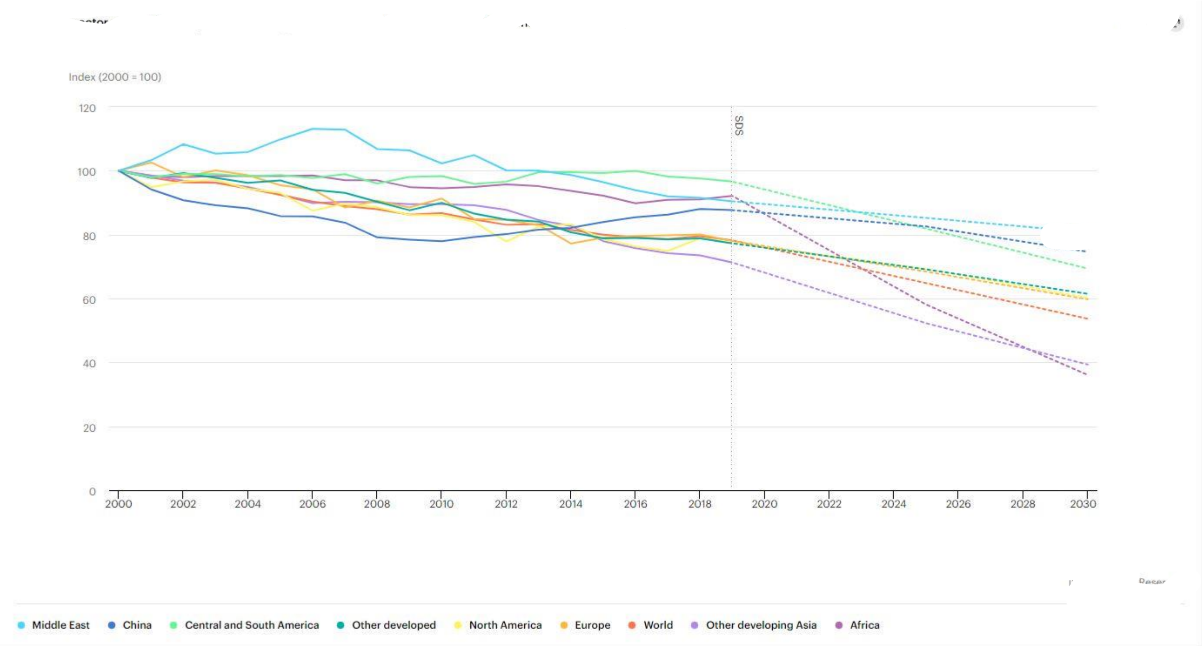


Figure 8: Building sector energy intensity around the world.[34]

Policies for Building have been amending or new policies have been introduced. There were policies regarding lighting pieces of equipment. So old incandescent lamps were replaced with LED lights, but the results were not very impressive. So, from most of the policies, the rate of improvement in recent years is 2-3% only.

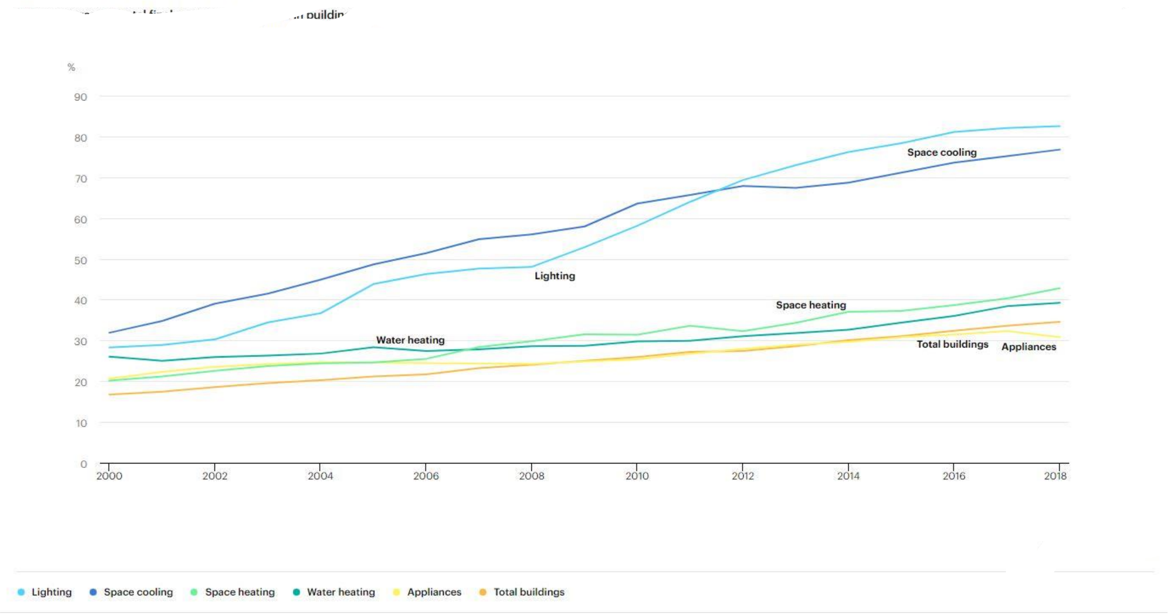


Figure 9: Final energy consumption in the building, 2000-18[35]

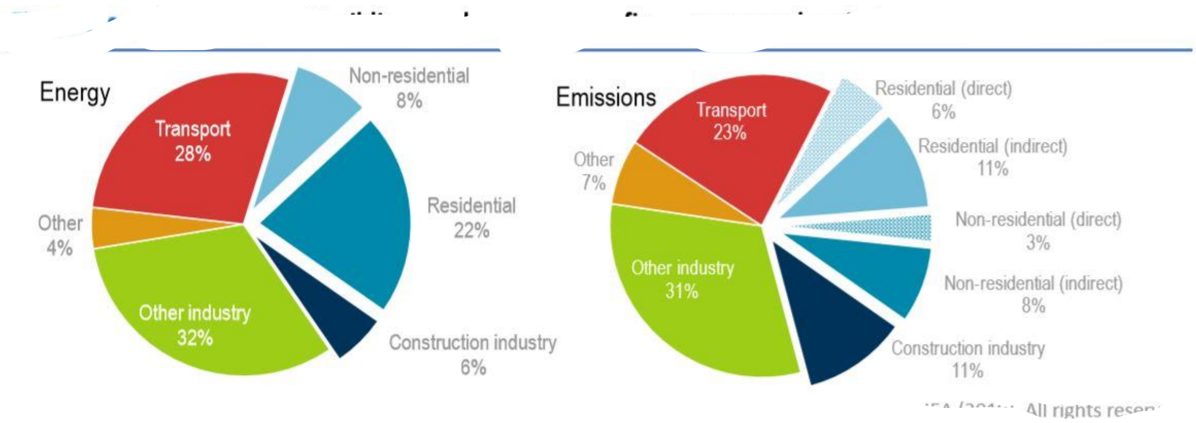


Figure 10: Global share of buildings and construction final energy and emission, 2018.[36]

As we can see that 36% of energy is consumed by the building industry globally. If we also include other minor factors, then it contributes around 40% of global emissions and this can be seen from figure10.

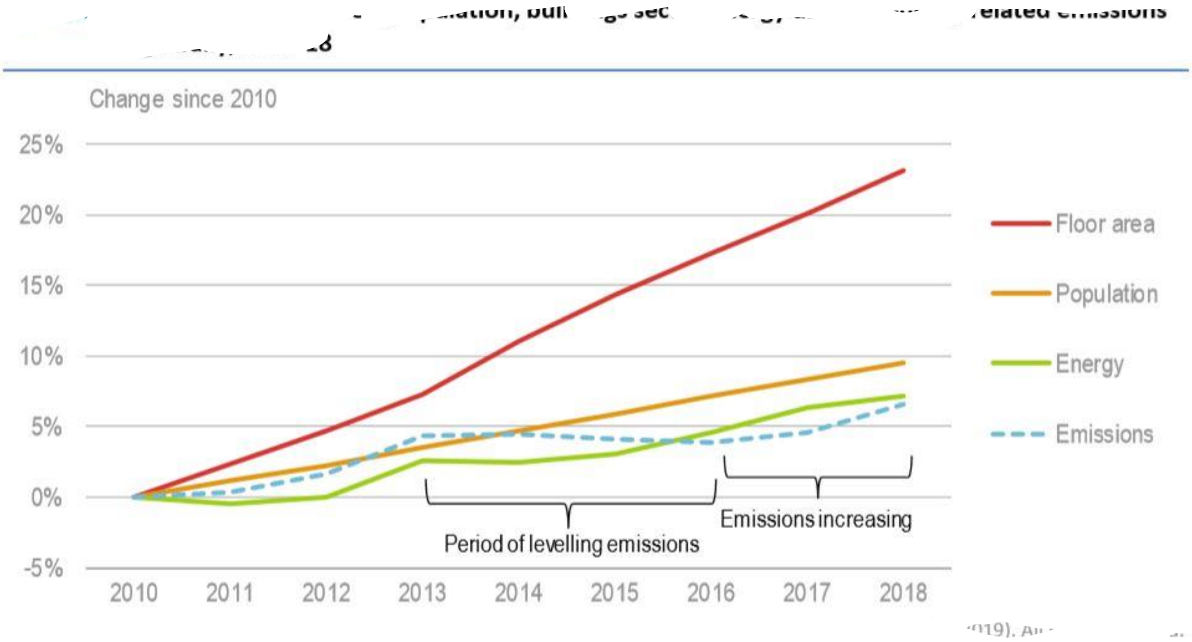


Figure 11: Global energy-related emissions as per floor area, population, building sector energy use.[37]

Although there is an improvement in the efficiency of the household appliances and types of equipment, which leads to the reduction in energy consumption increasing demand for cooling in hot regions again increases the energy demand and thus overall energy saving does not seem significant. Developing countries with hotter climates have shown a significant demand for energy in cooling. And in recent years due to the heat waves, the demand for cooling is also required mainly in western and southern Europe. There is around a 33% increase in energy demand for cooling during 2010-2018.[1]. This means that cooling demand since 2010 increased by 25% and roughly 1.6 billion air conditioning devices are in buildings around the globe.

The market for cooling units is greater in countries with an average global temperature of more than 35-degree Celsius and only 8% of 2.8 billion people living in an average temperature greater than 25 degrees Celsius are using cooling devices.

This demand for the cooling and heating of buildings can be reduced by passive and local design adaptation, nature-based design, and solutions. Association for International Passive house suggested that if the houses are made on these principles, then we can save up to 90% of the energy used for heating and cooling.

Table 1: Global change in Energy consumption in % from 2017-2018.[4]

Space Heating	-2%
Lighting and appliances	-1.4%
Space Cooling	+2.7%
Warm water, cooking & appliances	Nearly no change

The energy consumption in space heating, lighting, and appliances was reduced but increased for space cooling.

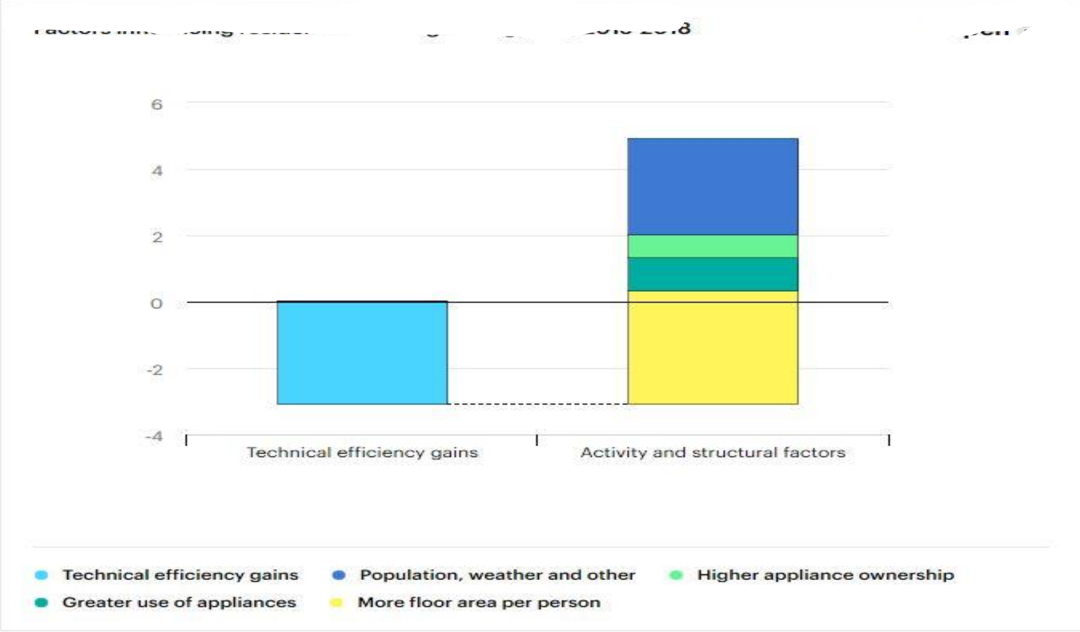


Figure 12: Factors influencing residential buildings energy use, 2015-18.[38]

Building Energy Codes- Energy codes are a subset of a broader collection of written legal requirements known as building codes, which govern the design and construction of the residential and commercial structure.[17]

It has been seen that around 2/3rd of countries are lacking building energy codes in 2019 and these are only the mandatory codes only. This means that around 5 billion m^2 of the area has been built last year only without the mandatory performance requirement. So, the mission of getting Sustainable Development Scenario (SDS) is not going to achieve if we are neglecting the mandatory regulation and building codes. The floor area has expanded more than 65% since 2000 and the energy use has also improved by 25% which is not a surprising result.

These codes are some of the proven methods to reduce energy consumption in buildings.

Some developing nations are coming forward and making different policies. Like in 2018, the government of Argentina launched the national Energy Efficiency and Renewable Energy in Social Housing habitability standard. India also took part in late 2018 and built its first national model building energy code for residential buildings.

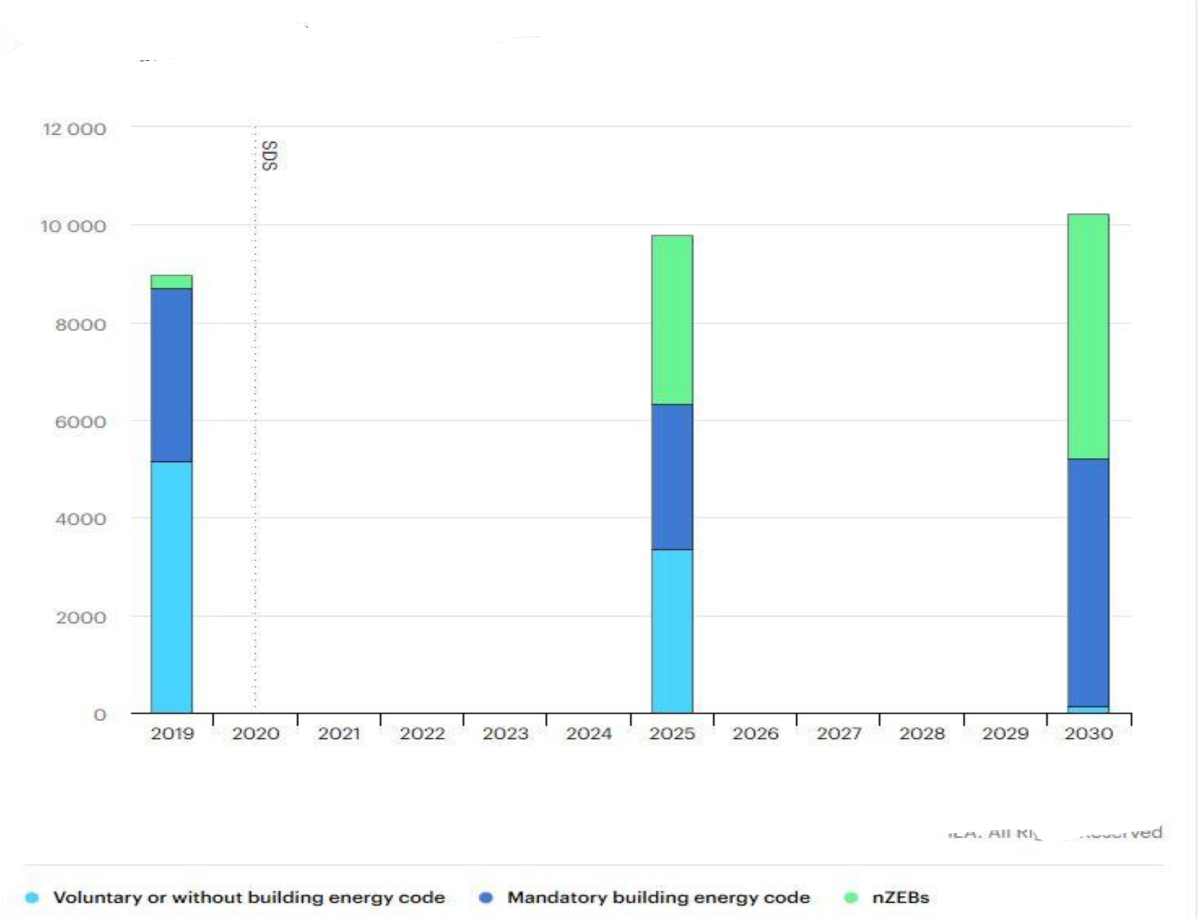
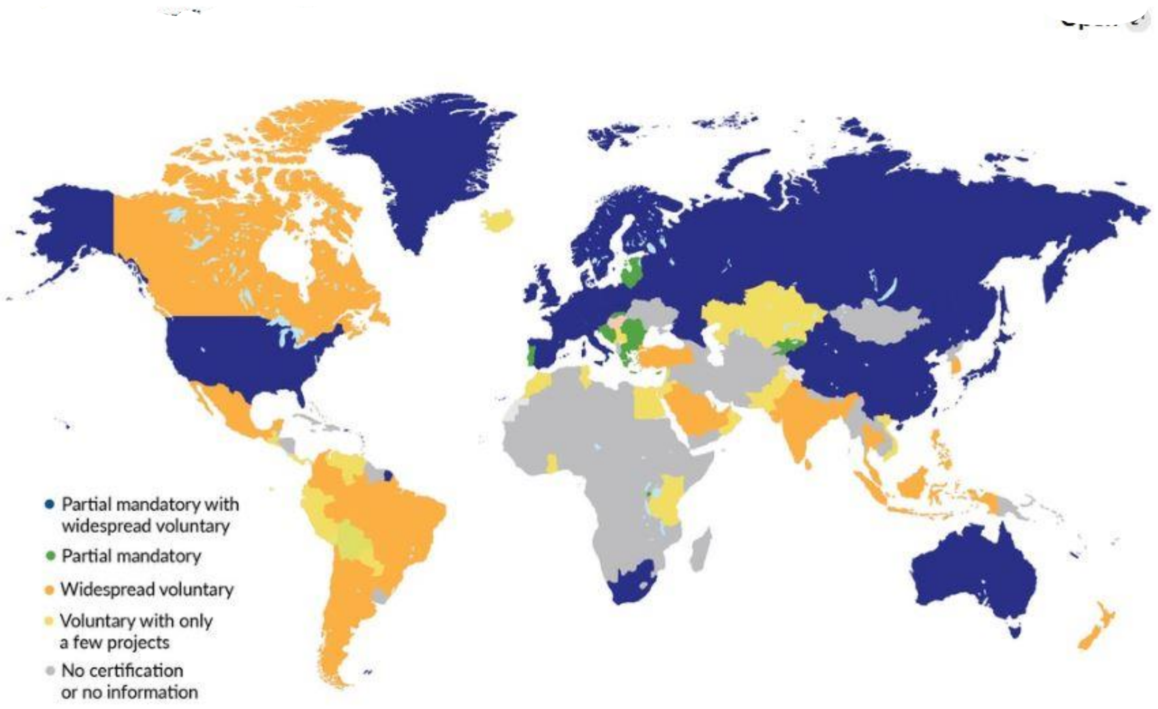


Figure 13: Global building construction area by the type of building code in SDS, 2019-30.[39]

So, 85 countries have building energy certification in 2019. Half of these nations have mandatory certification policies and the rest had voluntary certification policies or programs.

Some countries like India and Rwanda have introduced some initiative programs like Eco-Niwas Samhita and Green Building Minimum Compliance System respectively. These new initiatives are supported by World Green Building Council.

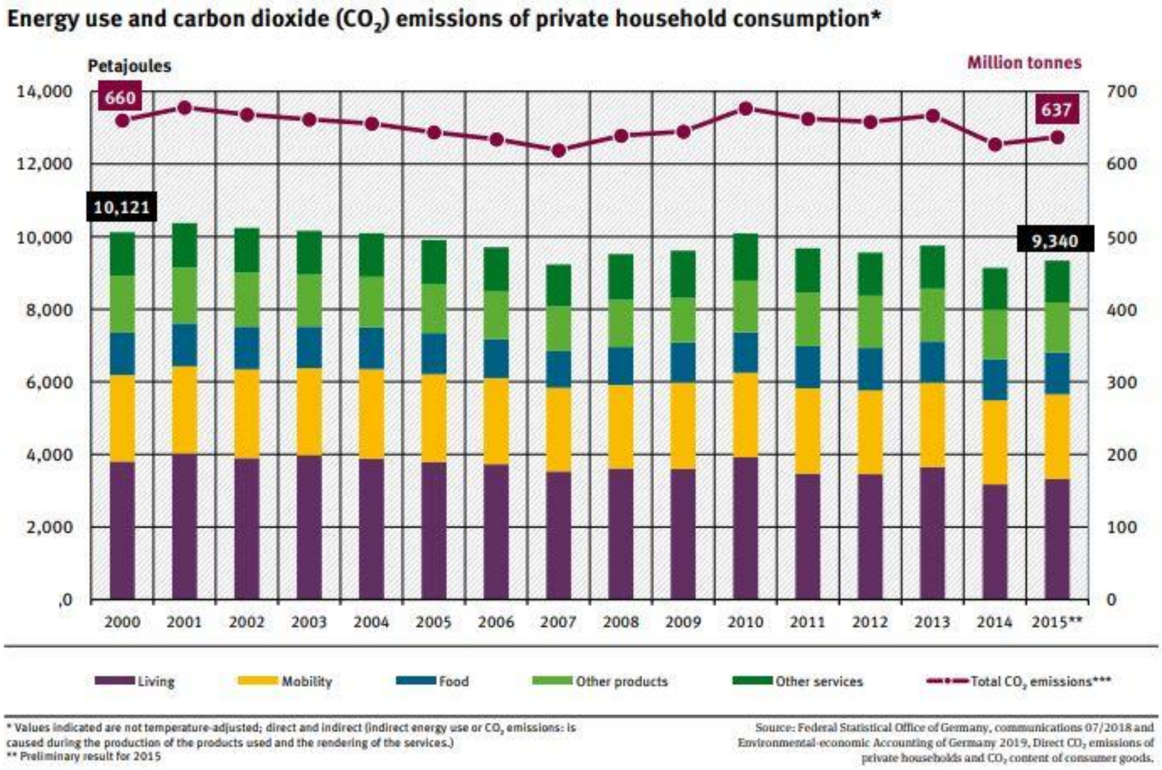


This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Figure 14: Building energy certification programs by jurisdiction, 2018-19[40]

Every country that took part in Paris Climate Summit has to announce or show their report of emission so that the target of getting 2 degrees Celsius of less temperature can be fulfilled till the year 2100. NDCs of 2018-19 focused on fuel conservation and phasing out inefficient products and equipment, also on improving buildings' performance codes and standards.

Another energy consumption section in buildings is appliances and equipment. These appliances and equipment showed no significant reduction in energy demand. Only one-third of appliance energy use today is covered by Mandatory Energy Performance Standards (MEPS). In 2019 the demand for energy for household appliances reached 3000 TWh which accounts for 15% of global electricity demand in buildings.



Energy use and carbon dioxide (CO_2) emissions of private household consumption*

* Values indicated are not temperature-adjusted; direct and indirect (indirect energy use or CO_2 emissions: is caused during the production of the products used and the rendering of the services.)
** Preliminary result for 2015

Source: Federal Statistical Office of Germany, communications 07/2018 and Environmental-economic Accounting of Germany 2019, Direct CO_2 emissions of private households and CO_2 content of consumer goods.

Figure 15: Energy use and CO2 emissions of private household consumption in Germany.[24]

According to a lot of studies and research, it is shown that the infrastructure of this world is responsible for maximum energy consumption. According to Global Energy Statistical Yearbook 2020, there is a consumption of nearly 24000 TWh of only electricity consumption. Data mention on European Environment Agency [2] site shows that in 2017 households and industry consumed 27% and 25% of energy consumption.

If we consider the fuel type then energy consumption in the EU increased in every fuel type (2016-2017). Oil accounted for the largest share of total final energy consumption in the EU, with 37.2 %, followed by electricity (22.7 %), natural gas (22.6 %), other fuels (15.1 %), and solid fuels (2.5 %). Even the US Department of Energy states that buildings consume about 40% of all energy used in the USA.[4][5]. In Germany, buildings consume 35% of total energy.

We can now discuss some types of building concepts. It is important to discuss because some of these concepts can help us achieve the target of reducing energy consumption, CO2 emission, or even to develop an ideal building design.

There are 9 different Building concepts:[6]

- Passive buildings
- Active buildings
- Net Zero Energy buildings
- Nearly Zero-energy building
- Positive energy building
- CO_2 Neutral building
- Circular building
- Healthy building

- **Passive Building**: The idea of Passive building is to reduce energy demand as much as possible. So, a building is called be passive building if the annual heating demand is less than 15 Wh/m^2. and the total energy demand for heating, cooling, appliance, hot tap water, etc is less than 60 Wh/m^2.

  To achieve that, a high level of insulation is required. High-efficiency glazing should be used and the ventilation system should apply heat recovery. This means passive buildings or houses required almost no heating and cooling system. The heat energy produced by appliances and humans should be enough to heat the building. And for cooling, the house should be designed in such a way the cooling required for a house can be taken from cold night air or air-cooled in underground pipes.

- **Active Building:** A building that emphasizes the use of renewables. The number of renewables on-site and off-site increases and smart controls are used to make the best use of it.

  What we can do is include controls inside the building, for example, Solar Blind controls. Also taking into account energy market price, when to buy, and when to sell which type of energy. We can say that the Active building concept is building optimization.

- **Net Zero Energy Building:** The building shows the balance between the energy consumed by the building and renewable energy produced and used within the building.

- **Nearly Zero Energy Building:** These buildings have slightly deviated from net-zero energy building which means that the energy demanded in the building is slightly greater than that of energy produced by the building.

  For instance, European guidelines indicate a maximum imbalance of 45KWh/m^2. The definition may also vary from place to place as well.

- **Positive Energy Building:** This building is just the opposite of a nearly zero energy building. This means that more energy is produced on-site (by renewables) than consumed.
- **CO_2 Neutral Building or Carbon-Neutral Buildings:** If a net-zero building uses only renewable energy this means they produce no carbon during the operation of the energy system and can therefore be called Carbon-Neutral Building.
- **Circular Building:** When not only the energy usage is carbon-free but also the construction material, processes, and materials used in the HVAC are also carbon-free.
- **Healthy Buildings:** The concept of a healthy building depends on various factors. Indoor air quality, quality of natural light and artificial lights, quality of the material used in the building, etc are some of the factors.

Comfort in the Building:

Various factors determine the comfort level of the building.

- Thermal Comfort: as described in ISO 7730 standard [19] – Thermal comfort is the state of mind that expresses satisfaction with the thermal environment. It can be expressed into observable parameters.

  These expressed and observable parameters are Air Temperature, Relative Humidity, Average radiation temperature, like wall temperature, also air velocity, metabolic activity, and the type of clothing the occupant is wearing.

  Indoor temperature is the most important parameter. It may vary from season to season and time to time during the day. It is very complex to decide whether which temperature is supposed to be comfortable temperature because a person with a suit may feel uncomfortable in 24-degree Celcius but a person with Tshirt can feel good and comfortable that is why indoor temperature comfortability is difficult to define but still we can say that in between 18-24 degree Celcius can be considered comfortable depending on the scenario.

2.1 Layout of Buildings

Buildings are generally made up of several different parts. They are categorized on a different basis. It acts as an envelope between humans and Environment. We can say that it is a boundary between conditioned and Unconditioned Environments. It includes roofs, exterior walls, roof windows, entrance doors, windows, curtain walls, and floors.

To build the infrastructure we need materials. There are a lot of different materials for the Envelop only which include: Aerated Concrete, Hollow and solid Bricks, Wood, Concrete[25][26]. And then we have insulators that help in controlling thermal conductivity and these are Basalt wool, Glass wool, Slag wool.

All these materials are used to build multi-layer boundaries to keep the thermal stability of the buildings. So that the building does not lose heat through every part of the building. The thermal process in the wall depends not only on the internal and external air temperature but also on many other factors. Therefore, the complexity of the process makes heat conservation in the room to be an actual problem. And a rough estimation of heat loss in the building is also shown in the image below:

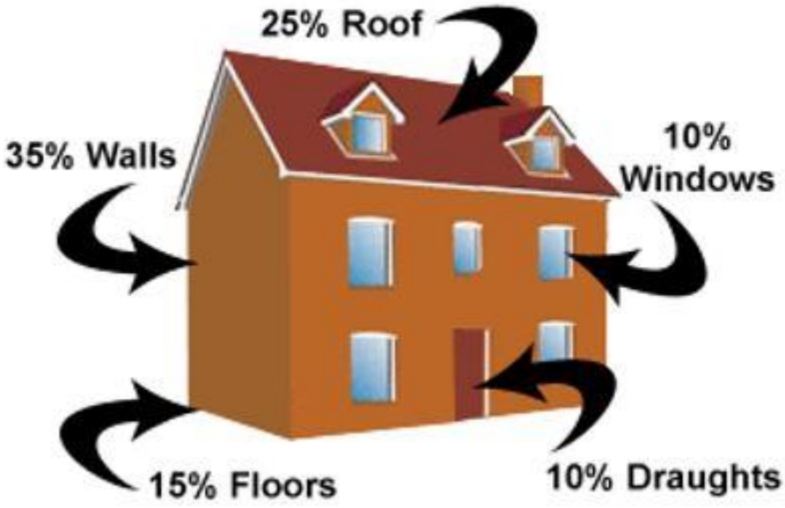


Figure 16: Heat loss in the building by the envelope.

To control and minimize these losses we need to know every property of the material used in the buildings and also have to study the heat transfer processes.

2.2 Basic Energy Calculation :

There are 4 different ways through which we can study the energy transfer process in the building.

1. Transmission.
2. Ventilation and Infiltration.
3. Solar Gains.
4. Internal Heat gains.

1. Transmission Losses: These losses occur through the building envelope.

Thermal calculation of building envelop is based on Fourier's Law[8]:

$$q = - \lambda . \Delta T \qquad (1)$$

Where q is specific heat flux [W/m^2]

T is the temperature which does not vary with time, [^{o}C]

λ is the thermal conductivity coefficient of the particular material.

And now Newton's law of heat transfer[16]:

$$Q = \lambda(\mathrm{T_i} - T_o). A \qquad (2)$$

Where:

$\mathrm{T_i}$ – Internal air temperature[^{o}C]

T_o – the average monthly outdoor air temperature[^{o}C]

A – Surface area of the wall, [m^2]

Q – heat flow rate, [W]

Thermal resistance

Due to the multilayer walls consists of different layers, the coefficients λ, c_p, ρ is changed discretely. With a great number of layers, the discrete distribution can be replaced by continuous distribution, and from summation turn to integration of continuous distribution [9].

$$R = \Sigma \frac{\delta_i}{\lambda_i} = \int_0^x \frac{dx}{\lambda(x)} \qquad (3)$$

Where R is Overall thermal resistance [m^2 C / W]

$$R = \frac{1}{\alpha_i} + R_1 = R_2 + R_3 + \cdots + R_n + \frac{1}{\alpha_o} \qquad (4)$$

R_n is the thermal resistance of the wall material

Where α_i is inner surface heat transfer coefficient of the building envelop, W/ m^2 ^{o}C

α_o is outer surface heat transfer coefficient of the building envelop, W/ m^2 ^{o}C

U – Heat transfer coefficient (W/m^2 ^{o}C)

Or

$$Q = U.A\,(T_i - T_o). \qquad (5)$$

And

$$U = \frac{1}{R} \qquad (6)$$

Thermal bridges: Heat loss due to thermal bridges can be calculated by the formula below:

$$Q_{bridge} = L\,\Psi\,(T_o - T_i) \qquad (7)$$

Where,

Q_{bridge} = heat flow [W]

Ψ = linear thermal transmittance of the thermal bridge [W/mK]

L = length thermal bridge [m]

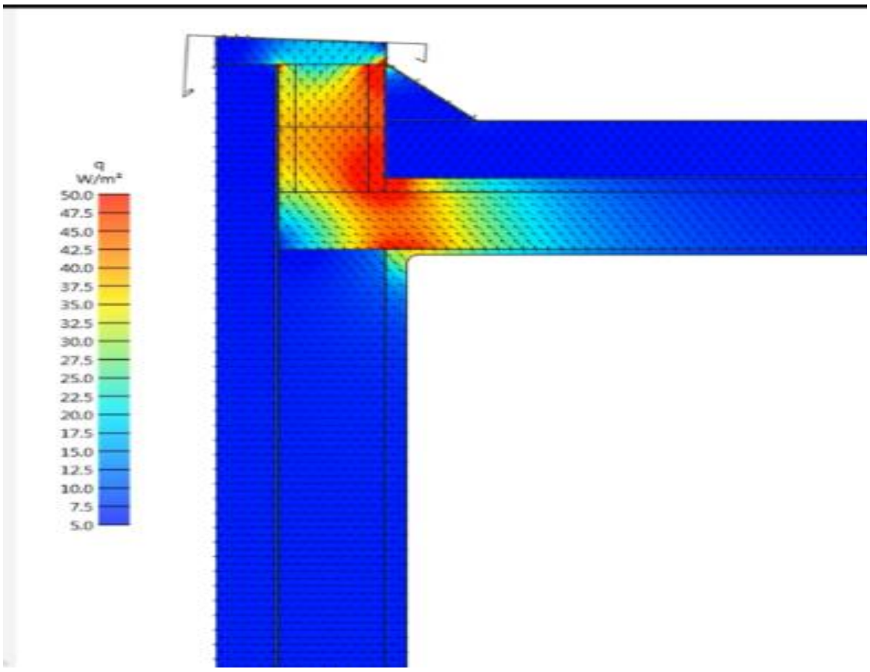


Fig 17: Thermal Bridge

The proportion of heat loss due to thermal bridges is typically 10–15 %, this can increase up to 30% in very well insulated buildings with poor design or realized construction details. From figure 17 it can be seen that at the joints or connection points the thermal losses are significantly more than the rest of the areas.

2. Ventilation and Infiltration Losses[12]: The difference between ventilation and infiltration is that ventilation is a controllable thing but infiltration is uncontrollable because it occurs due to leaks, gaps, cracks, through porosity in the wall, doors, windows of the building. So the losses that occur due to infiltration can only be reduced by reducing the leaks or by using different materials.

   There are different ways of ventilation, some of them are:

   - Natural Ventilation: It can be done by just regulating the openings of the building.
   - Forced Ventilation: We use a mechanical system for air circulation.

   Under forced ventilation, there is Mechanical Exhaust, Mechanical supply, and Mechanical exhaust + Mechanical supply with Heat Recovery.

   Energy loss can be calculated as:

   without heat recovery

   $$Q_{vent+inf} = (m_v + m_i) . C_p (T_o - T_i). \qquad (8)$$

   with heat recovery

   $$Q_{vent+inf} = ((1- \eta)m_v + m_i) . C_p (T_o - T_i). \qquad (9)$$

   This heat recovery works when there is a temperature difference between 2-5 ^oC.

   $Q_{vent+inf}$ - Heat Flow [W]

   m_v - mass flow rate of ventilation [kg/s]

   m_i - mass flow rate of infilteration air [kg/s]

   C_p - specific heat of air [J/kgK]

   T_o - Outdoor temperature [^{o}C]

   T_i - Indoor temperature [^{o}C]

η - Efficiency

T - time [h]

Mass flow of ventilation [Kg/s]

$m_v = \rho_{air} . V$ (10)

ρ_{air} is 1.2 kg/m^3

Mass flow of infiltration air [Kg/s]

For old buildings: $V_i > 1$ ACH

Air – tight buildings: $V_i \sim 0.2$ ACH

(1 Air Change per Hour = indoor volume of the building)

C_p : Specific heat of Air : 1000 [J/kgK]

Energy consumption of Ventilator

$$P_{vent} = \frac{V.\Delta P}{\eta} \quad (11)$$

V : air volume flow rate [m^3/s]

P : pressure drop through ventilator [Pa]

η : Efficiency or rendement {ventilator + motor} ~ 0.5-0.75

3. Solar heat gains: Estimation of Solar heat gains

For windows

$Q_{sol} = f . g_{shade} . g_{glass} . A_{window} . P_{sol}$ (12)

Where:

$P_{ool:}$ global solar radiation on a vertical plan on the same orientation as the window [W/m^2]

A_{window} : surface of the window [m^2]

g_{glass} : solar factor of the glazing

g_{shade} : solar factor of the solar blinds

f : reduction factor for heavy buildings (light building: f=1; heavy building: f=0.85)

this is the simplified method to calculate solar gains only by taking the window into account. Global solar radiation consists of direct and diffused radiation. Solar factor describes the part of the solar radiation that is transmitted through the glass and blind.

4. Internal gains: every building has occupants and equipment. Due to various activities, there is heat generation is considered as internal heat gain.

Table 2: Heat gains [in W] from humans.

Rest	Office work	Filing standing	Cooking/walking	Dancing/sports
~100	~117	~144	~180	~360

Table 3: Heat gains of Lighting bulbs [lumen/W]

Incandescent	Halogen	Compact fluorescent	LED	Induction	Fluorescent tubes (argon)	Fluorescent lamps (sodium)
~10-13	~13-18	~25-60	~45-60	~60-90	~55-95	~100-130

Table 4: Heat gains of Power appliances [W]

Computer/Desktop	Monitor	Laptop	Phone charger	Television	Fridge
~65	~25	~40	~12	~91	~310

So, all the heat losses and heat gains are important to consider and are shown in figure 18. So, when losses are greater than gains then heating is required and when losses are less than gains then cooling is required.

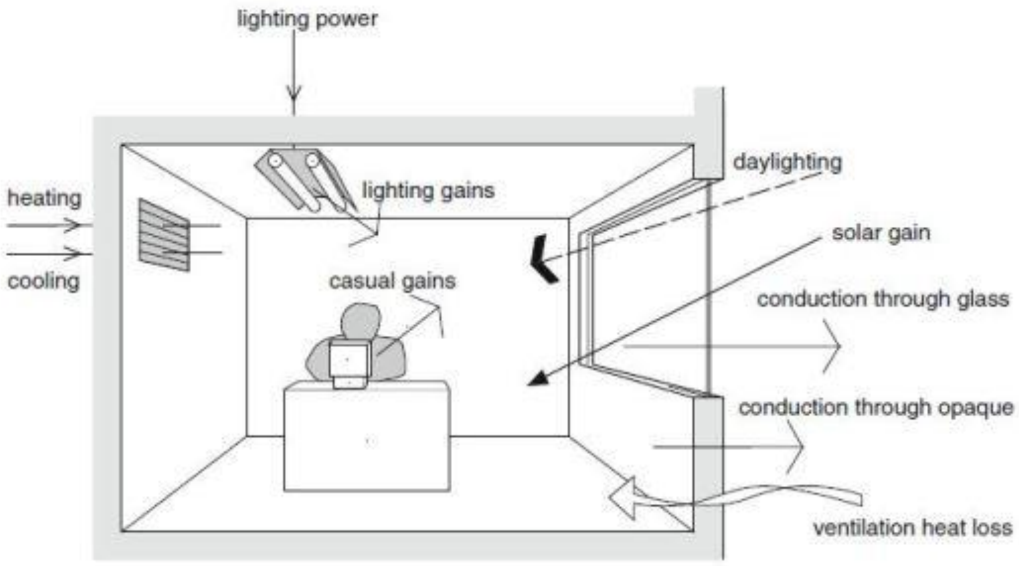


Figure 18: Possible losses and gains in the building.[27]

2.3 Energy Utilization in the buildings around the world

In the different parts of the world, energy utilization in Buildings is used for different purposes. Mainly they are used for heating, cooling, ventilation, running electric equipment, and for warm water. For example, in Africa, the Middle East, Southern Europe, and in major parts of Asia continent it is used for Cooling the space. And in Europe, Southern Asia, Southern part of North America and in some countries of South America it is used for heating purpose.

This cooling and Heating utilize a lot of amount energy in the energy sector. Some reports are even discussed further in detail explaining the energy use of every sector, the type of energy use, amount of CO2 production by that energy.

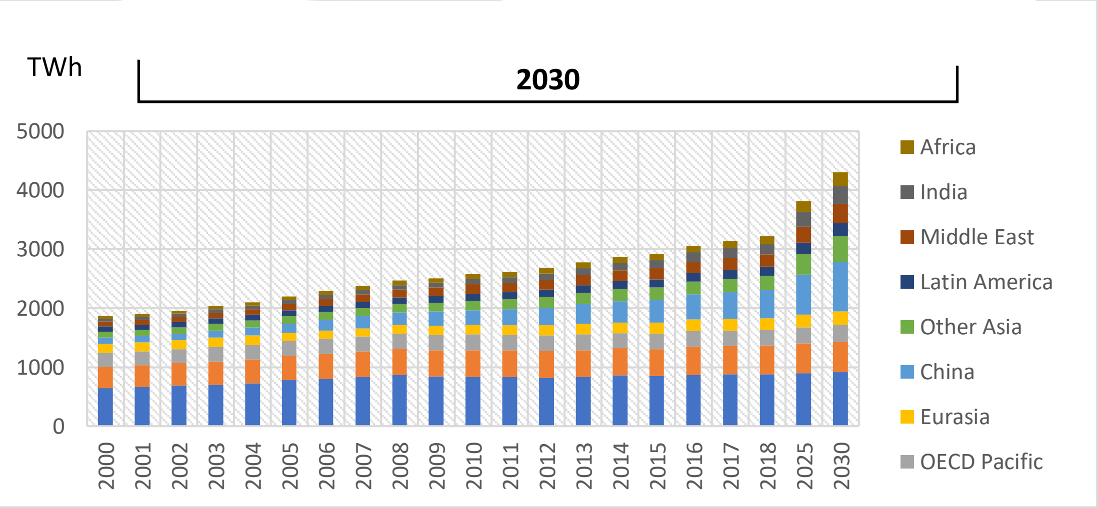


Figure 19: Household appliances and plug loads by region in SDS, 2000-2030[41].

It is very difficult to find out the overall CO2 production occurs due to buildings because the building starts from the production of basic components required to build a building like cement, bricks, concrete, steel, windows, doors, and many other components and that is why it is very difficult to find out the CO2 production. But by the amount of direct energy consumption, we can somehow estimate the CO2 emission from the buildings.

2.4 Global Importance

Studying the use of Energy in the Building sector has a significant role in the global environment as well as in the Energy production sector because 30-40% of the total energy produced is used by the building [4]. And Energy produced does not always produce in clean ways only. The conventional ways generate many different gases including CO2 which is our major concern because it is a greenhouse gas and is helping to increase the global temperature of Earth. Resulting in Water levels rising, extinction of different natural vegetation and wildlife, the sinking of different islands and countries, and many other important incidents are happening.

2.4.1 Energy Efficiency Improvement and situation

To improve the situation there are different methods. Energy production should be done in a clean way using solar, wind, thermal, geothermal, tidal. Although there will be an initial amount of CO2 emission takes place but then, in the long run, there will be no emission, or a very small amount of emission takes place. But the question is if it is cost-efficient and has enough production capacity. The answer is no because there is still a huge number of resources like coal and oil available so switching to 100% clean and expensive technology is not visible. Although big economies are putting their efforts to produce as much clean energy they can, for example, India has one of the largest solar farms named Bhadla solar park with a capacity of 2245MW followed by Chinese solar park with a capacity of 2200 MW in the province of Qinghai [22,23]. Again, China is having the world's largest wind farm with a capacity of 20000 MW followed by the American Shepherd fla wind farm with a capacity of 845MW. So these initiations are being taken by the countries around the world but this is not enough to fulfill the energy demand.

So, the next thought is by improving efficiencies, we can reduce the energy demand.

And if we are discussing the energy demand in buildings then we have different things to discuss like improving the building architecture, improving building envelop, and using energy-efficient equipment and instruments. This goes a bit expensive in terms of cost but in the long run, they are worth investing in.

we can make building energy-efficient or use non-conventional ways to make building net-zero or nearly net-zero Buildings. This can be done by using already discussed technology like solar, wind, heat pumps.

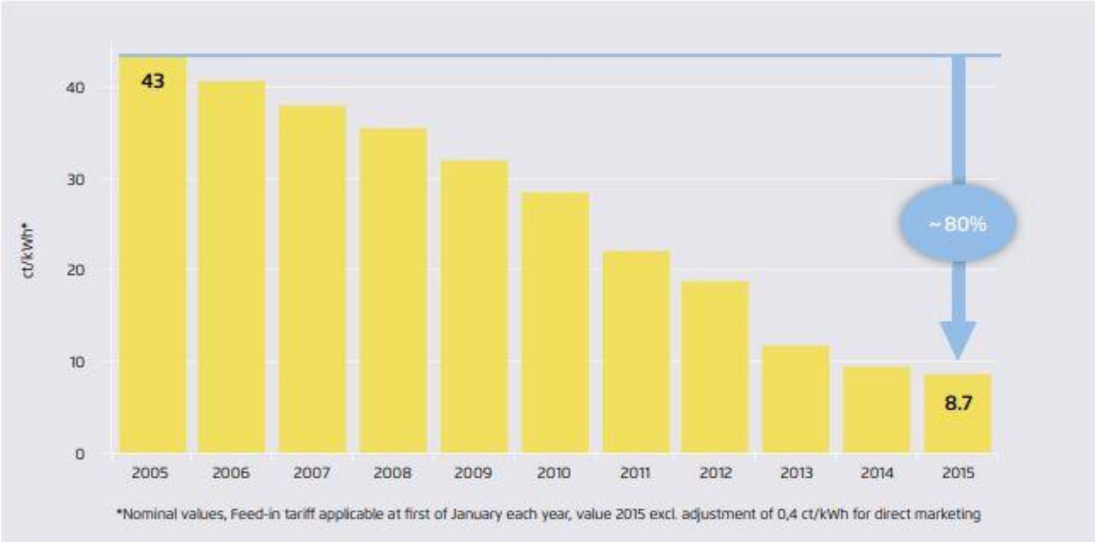
Most of the time these are not enough so we also take advantage of our surroundings.

2.4.1.1 Solar

One of the major sources of energy is Sun. It not only provides direct energy to Plants and Animals but we have technologies to utilize that energy in other forms and at different places. In a bigger frame, solar energy is used for electricity production and for thermal. Although solar energy is like a never-ending source it has its limitations on earth. Geographical location and weather condition has a great influence on solar radiation.

Even solar panels are not very efficient. On average the efficiency of solar panels is 15-25%. In 2019, research at National Renewable Energy Laboratory, Golden, Colorado, USA created a world record for achieving 47.1% of the efficiency of a solar cell.

There is a significant reduction in the cost of solar photovoltaic production. In 2005 the feed-in tariff was 40 cents/kW and in 2015 it becomes 9 cents/kW which is around 80% of the price reduction in Germany. So one of the expensive energy sources has become one of the cheapest energy sources[13][20][21]



*Nominal values, Feed-in tariff applicable at first of January each year, value 2015 excl. adjustment of 0,4 ct/kWh for direct marketing

German renewable energy law, Agora Energiewende

Figure 20: Feed-in-tariff for new large-scale solar photovoltaic in Germany.[14]

2.4.1.2 Heat Pumps

These devices absorb heat from a cold space and release it to a warmer space. It needs outside power to operate. It is consisting of four main components – a condenser, an evaporator a compressor, and an expansion valve. Evaporator and condenser are nothing but just heat exchanger where evaporator act as a low-temperature heat exchanger and condenser act as a high-temperature heat exchanger. Compressors increase the pressure of the refrigerant which leads to an increase in temperature also. The expansion valve is a device where high pressure and temperature refrigerant passes through and due to its design, there is pressure reduction and so does the temperature.

It is mainly of two types depend on the input power required to operate: compression and absorption. The heat pumps are further classified as Air-Air heat pumps and Air – Water heat pumps.

It can be applied to ventilation, heating, and air conditioning devices either for heating or cooling.

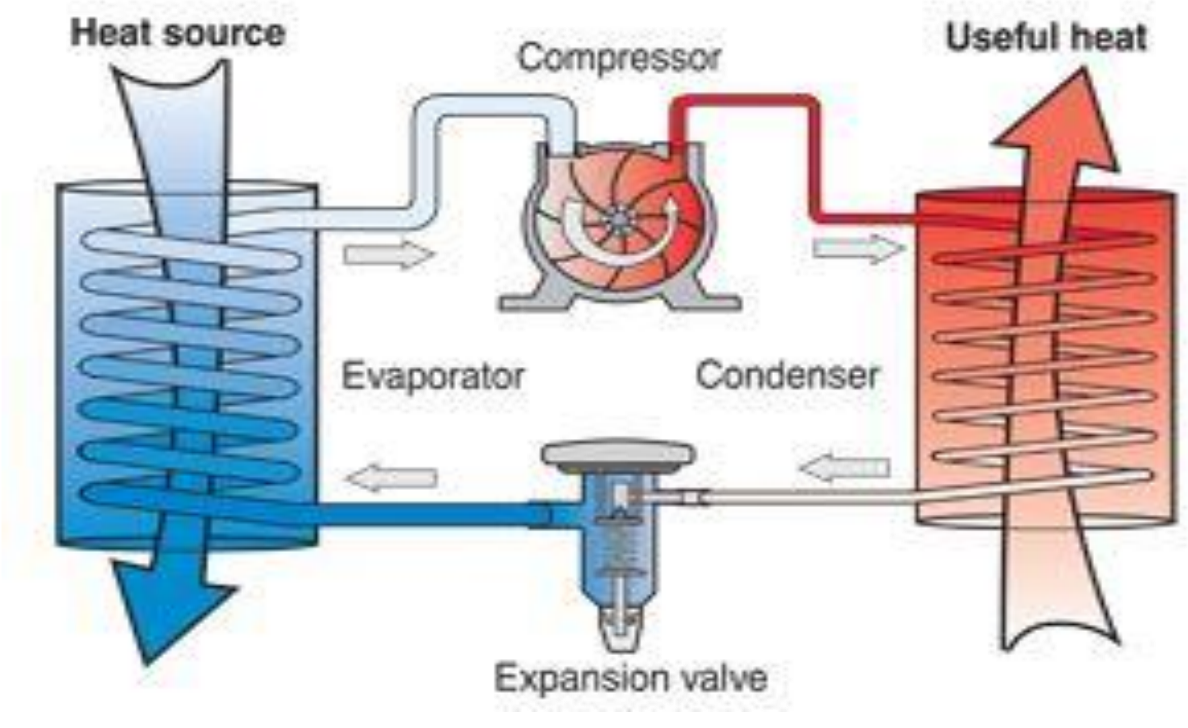


Figure 21: Schematic diagram of a heat pump.

So, the fundamental is that the heat moves from a higher temperature gradient to a lower temperature gradient and that is how the heat pump works.

In figure 21, a low-temperature liquid passed through the evaporator and absorbs the heat from the surrounding by evaporation at low pressure and leaves as low-temperature vapor. This refrigerant then passes through the compressor where there is a rise in pressure and temperature of the refrigerant. This refrigerant then passes through the condenser where it releases or rejects heat to the surrounding.

Then this reduced temperature passes through a valve called the expansion valve also called the throttling valve. Then, in this valve when the hot medium passes by then there is the pressure drop and as the pressure drops the refrigerant starts to evaporate in the valve, and this heat of evaporation is taken from the refrigerant itself and this leads to temperature reduction. And after the expansion valve, we have low pressure (liquid and gas) and low-temperature refrigerant.[18]

2.4.1.3 Thermal / Electrical Energy Storage

It comes into account because a lot of the time there is a very low demand for thermal and electrical energy and at that time the product can be usual, so we have extra energy left which go waste. On the other hand, there are situations where there is peak demand for both thermal and electrical energy. So, to overcome the situation the concept of energy storage is very useful.

For thermal energy storage, we have various technologies like – heat storage tank, Phase change material (PCM), Molten salt storage, heat storage in hot rock or concrete, Miscibility gap alloy technology, Solar Pond, Steam accumulator, Ice based technology, Cryogenic energy storage, hot silicon technology.

And for electrical energy storage, we have some technologies – Capacitor, Supercapacitors, Superconducting magnetic energy storage, Battery.[15]

3 Software used

The software used to do major design and calculations are IDA Indoor Climate and Energy.

Back in time, there used to be old mathematical models to calculate the energy demand of the buildings, and usually, they are only used for calculating the heating demand only.

But now computer-aided software and programs have been developed which are huge potential to simulate extensive input data and parameters. Some of the famous know energy modeling software are IDA ICE, Climate consultant, EnergyPlus, Design Builder, Trace 700, carrier HAP, TRNSYS, IES VE.

IDA ICE is one of the software which can simulate multi-zone structures. This software is under development since the 1980s and the developing institutes are KTH Royal Institute of Technology and Swedish Institute of Applied Mathematics.

Now it is under the company name EQUA simulation AB.

The software is very flexible. It has a huge database and if something is not available at the database then either we can import the data from an external source or we can feed the data manually by ourselves. In this work version, 4.8 is used which is the most up-to-date till now [10][11].

- The software is so handy that it provides the user a handy and familiar experience.
- It provides 2d as well as 3d models of any structure which helps in imagining and visualizing things and situations.
- The model also provides a feature of ESBO where the formation of the difficult and complex technical plant is easy and quick.
- In the same ESBO model, there is the flexibility of using various renewable energy sources like PV, Wind turbines, heat pumps.
- The models of IDA ICE are based on Neutral Model Format. The model is so transparent that there is a possibility to inspect all parameters and to control signals.

4 Case Study

The study is done on a student apartment that is in use and is in Garbsen Germany. It was constructed in 2019. It has 162 student rooms, 1 laundry room, 2 lifts, 1 common room, 1 office, 2 storage rooms, 1 warden living room. Every room has 2 lights, 1 in the bedroom and 1 in the washroom. Every single room is centrally heated. There are a refrigerator and Cooktop in every student room

The timetable of every student is quite similar because they all are university students which means they go to university from Monday to Friday for at least 6-8 hours and if we include other parameters like travel, groceries, the party then we can say that a student spent nearly 10-12 hour outside the room in a day.

While in the room person uses electricity for equipment. The refrigerator is on all the time while the cooktop is used normally for 1 hour each day. An average person uses 143 liters of water each day [7].

All the rooms are nearly identical, but some are bigger than others.

There is one main door to enter the room. The bathroom is attached to the room and is separated by internal walls and doors. There is a very large window in every room which is 2m * 2 m. Every room is having a bed, a chair, a table, a wardrobe and some brackets for storage.

The input weather data is taken from a database of IDA ICE shown in table 5:

Table 5: Building location along with wind profile.

Location/climate	Wind profile
Hannover(wunstorf)_103340	urban

4.1 Ground, Orientation, and Geometry

There are some standard values for thermal losses from the floor and those files are assigned in the software. It follows the European standard ISO 13370. We can see the building orientation in figure 22.

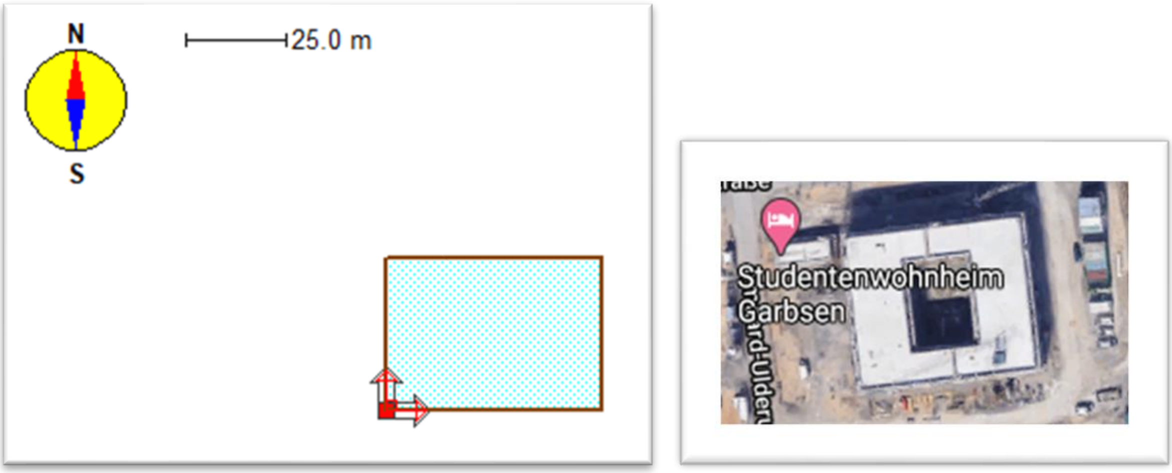
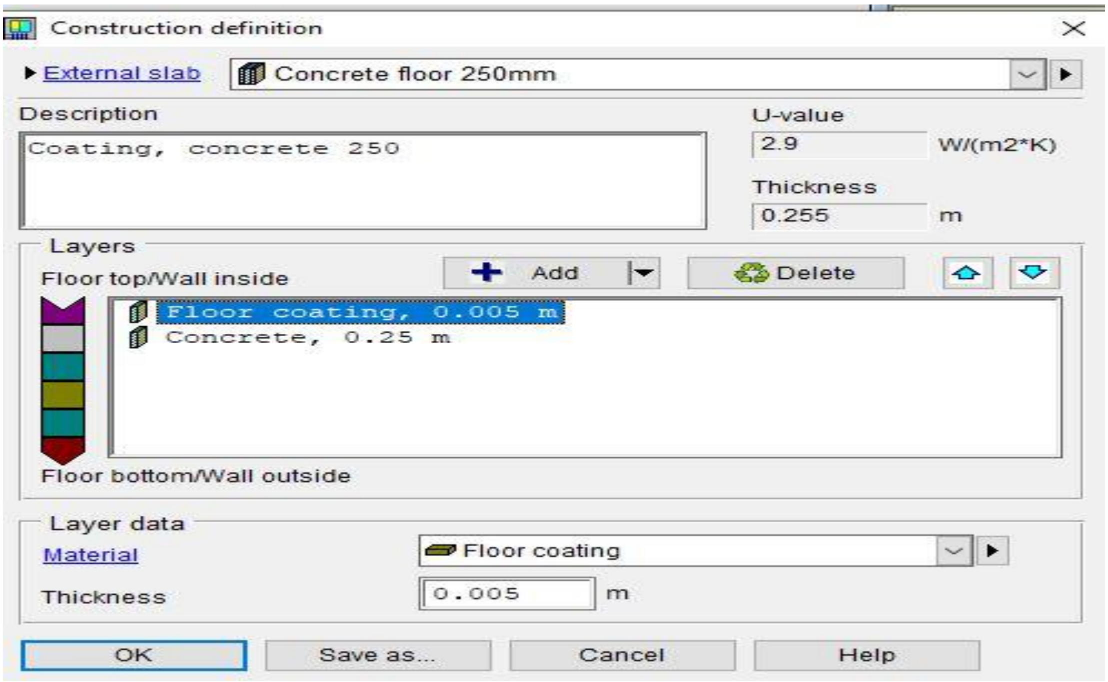


Figure 22: building orientation on the left and google satellite image on the right.

4.2 Material Used for construction:

Building envelop is the reason for most unwanted heat transfer. There are pre-defined materials that we can select from the database of IDA ICE with their mandatory properties necessary for the calculations.

The total ground slab thickness in model1 is 0.255m and the U value of the floor is 2.9 [W/m^{2}K] with a floor coating thickness of 0.005m as shown in figure 23. In model2 the slab thickness is 0.423m and having a U value of 0.1588 [W/m^{2}K].



External slab: Concrete floor 250mm

Description: Coating, concrete 250

U-value: 2.9 W/(m2*K)

Thickness: 0.255 m

Layers

Floor top/Wall inside

Floor coating, 0.005 m

Concrete, 0.25 m

Floor bottom/Wall outside

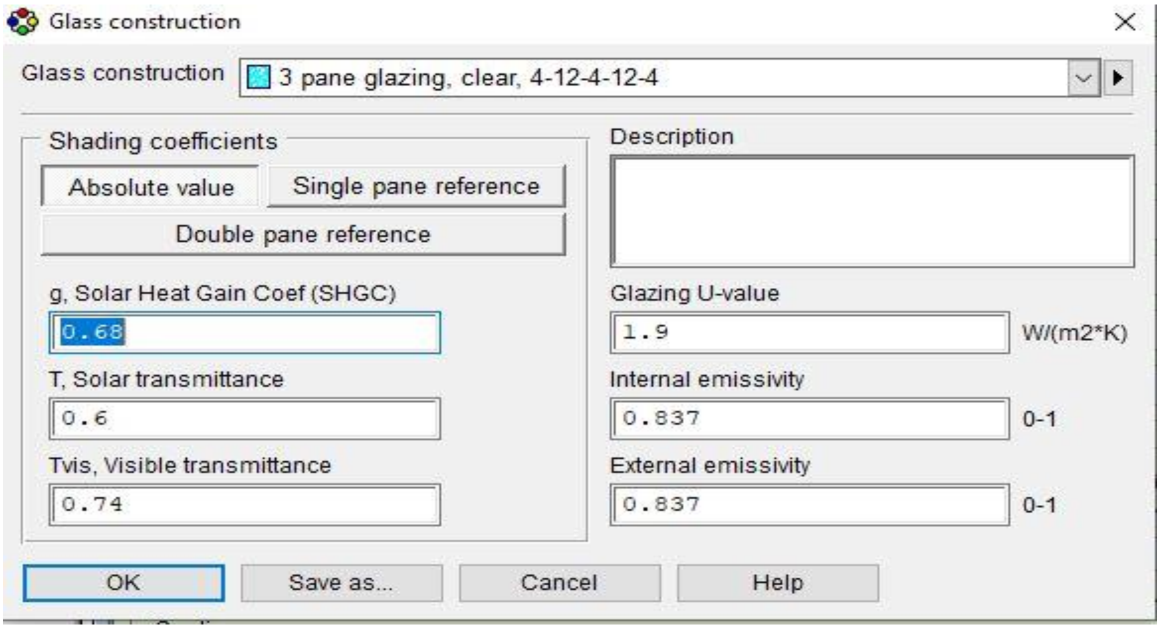
Layer data

Material: Floor coating

Thickness: 0.005 m

Figure 23: Floor slab tab with specification in IDA ICE.

Now let's talk about windows as shown in figure 24 here we have options to choose so we selected 3 planes playing window for model1 with properties, glazing U value of 1.9 [W/m^{2}K],



Glass construction: 3 pane glazing, clear, 4-12-4-12-4

g, Solar Heat Gain Coef (SHGC): 0.68

T, Solar transmittance: 0.6

Tvis, Visible transmittance: 0.74

Glazing U-value: 1.9 W/(m2*K)

Internal emissivity: 0.837 0-1

External emissivity: 0.837 0-1

Figure 24: Window tab with specification in IDA ICE.

And for model2 again 3 layer window with outer glass optitherm s3, with a cavity width of 15mm filled with argon, middle glass Pilkington again cavity of 15mm filled with argon and inner glass optitherm. The U value of this window is 0.6 [W/m^{2}K].

All of the other building parts like external walls, internal floor, the roof have different values and are discussed in table 7.

Table 7: Some of the U-values are shown.

ENVELOPE COMPONENTS	Model 1 U – VALUES (W/m^2 K)	Model 2 U – VALUES (W/m^2 K)
External wall	0.5372	0.2349
Roof	0.172	0.095
Internal floor	2.385	0.158
Inner Doors, entrance doors	2.194, 1.085	1.085

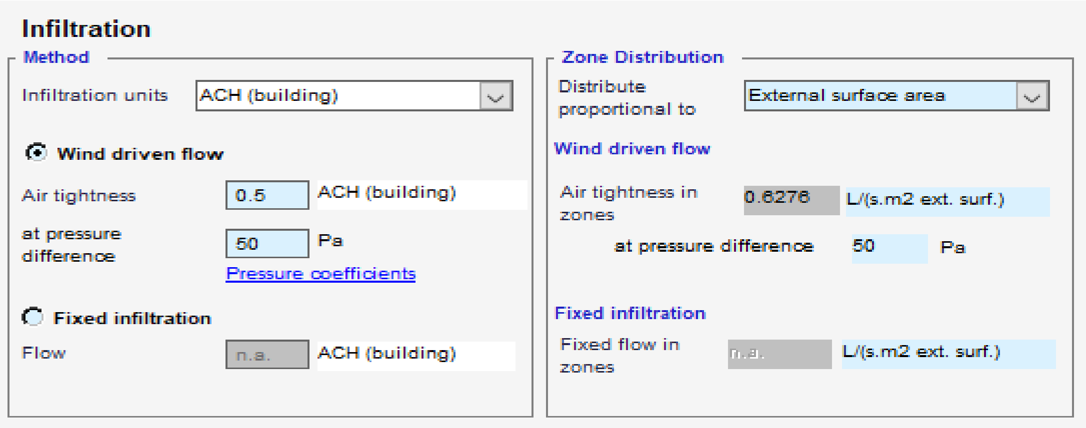
Windows (3 plane glazing)	1.9	0.6

The external wall in both cases is a sandwich of render and concrete with a render thickness of 0.01m on both sides which is about 0.27m thick.

The roof in model1 is insulated with insulation material of 0.2m thick and a concrete layer of 0.150m thick. And in model2 it has a thickness of 0.4m and 0.095 [W/m^{2}K] of U value.
Model1 has a joist floor with a thickness of 0.175m, using floor coating of thickness 0.005m. whereas model 2 has a concrete layer along with the light insulation which has a U value of 0.158[W/m^{2}K].
Entrance doors are made of wood and aluminum with light insulation and the overall thickness of the door is 0.035m. and internal doors are 0.04m thick.

4.3 Infiltration

Infiltration shows the amount of air leakage from the building.



Infiltration

Method

Infiltration units: ACH (building)

● Wind driven flow

Air tightness: 0.5 ACH (building)

at pressure difference: 50 Pa

Pressure coefficients

○ Fixed infiltration

Flow: n.a. ACH (building)

Zone Distribution

Distribute proportional to: External surface area

Wind driven flow

Air tightness in zones: 0.6276 L/(s.m2 ext. surf.)

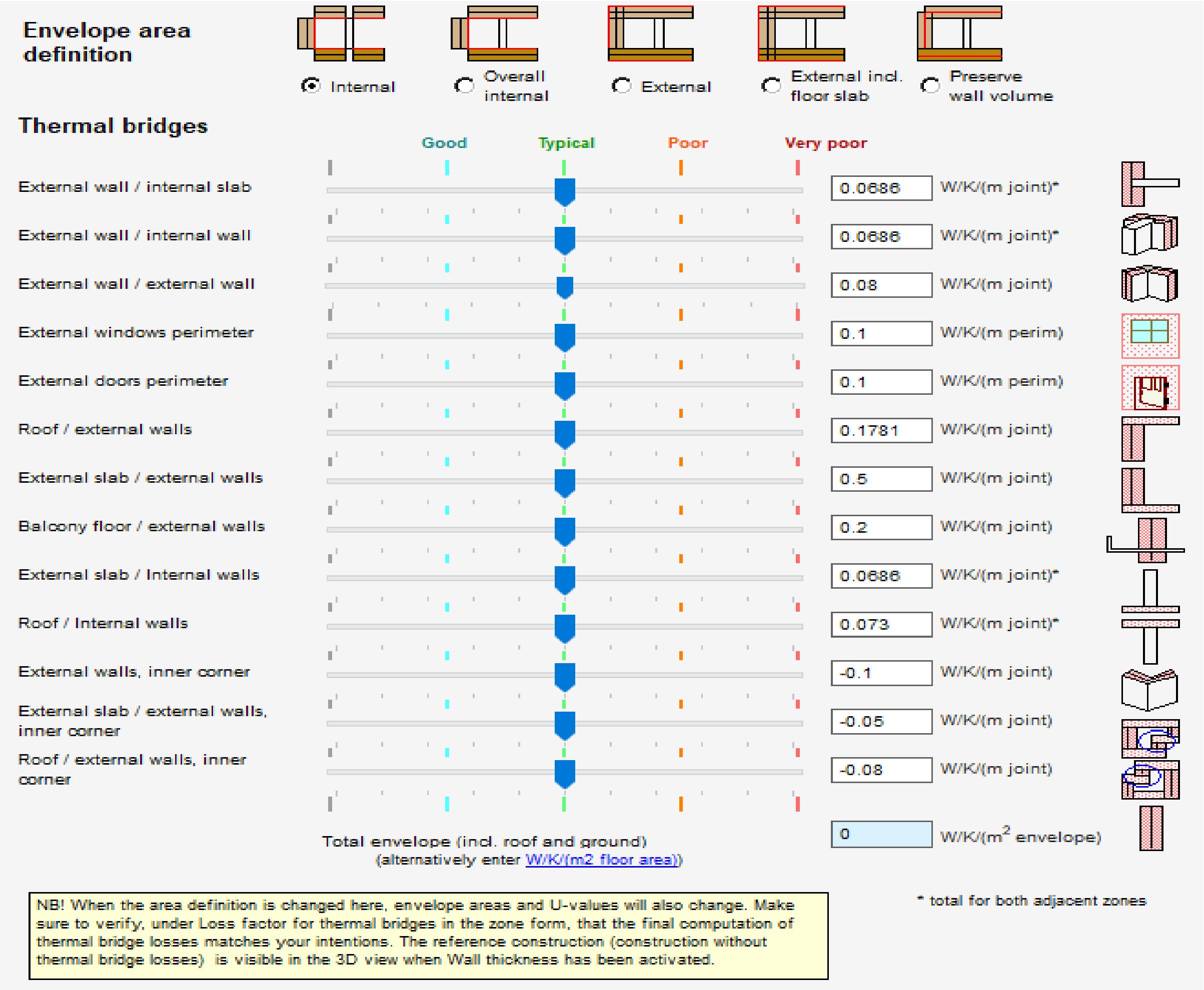
at pressure difference: 50 Pa

Fixed infiltration

Fixed flow in zones: n.a. L/(s.m2 ext. surf.)

Figure 25: Default infiltration popup of IDA ICE.

Thermal bridges are taken as typical and are shown if figure 26:



Envelope area definition

● Internal ○ Overall internal ○ External ○ External incl. floor slab ○ Preserve wall volume

Thermal bridges

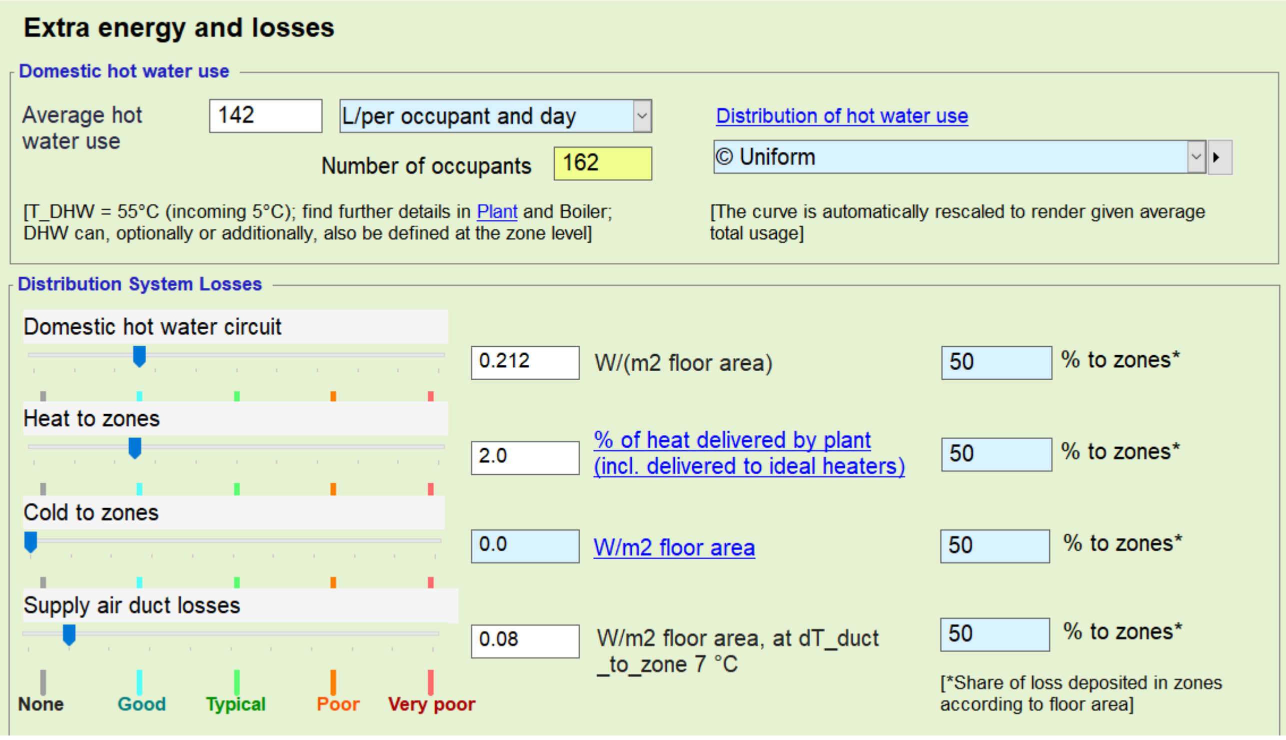
External wall / internal slab	0.0686	W/K/(m joint)*
External wall / internal wall	0.0686	W/K/(m joint)*
External wall / external wall	0.08	W/K/(m joint)
External windows perimeter	0.1	W/K/(m perim)
External doors perimeter	0.1	W/K/(m perim)
Roof / external walls	0.1781	W/K/(m joint)
External slab / external walls	0.5	W/K/(m joint)
Balcony floor / external walls	0.2	W/K/(m joint)
External slab / Internal walls	0.0686	W/K/(m joint)*
Roof / Internal walls	0.073	W/K/(m joint)*
External walls, inner corner	-0.1	W/K/(m joint)
External slab / external walls, inner corner	-0.05	W/K/(m joint)
Roof / external walls, inner corner	-0.08	W/K/(m joint)
Total envelope (incl. roof and ground) (alternatively enter W/K/(m2 floor area))	0	W/K/(m^2 envelope)

NB! When the area definition is changed here, envelope areas and U-values will also change. Make sure to verify, under Loss factor for thermal bridges in the zone form, that the final computation of thermal bridge losses matches your intentions. The reference construction (construction without thermal bridge losses) is visible in the 3D view when Wall thickness has been activated.

* total for both adjacent zones

Figure 26: Values of thermal bridges at all possible sections in the building.

Both the models also consider the losses that occur due to the distribution of hot water. It can be seen down in figure 27, where there is a description of water usage per person per day. Also, have some standard values of losses that occur in W/m^2 of floor area.



Extra energy and losses

Domestic hot water use

Average hot water use: 142 L/per occupant and day

Number of occupants: 162

Distribution of hot water use: © Uniform

[T_DHW = 55°C (incoming 5°C); find further details in Plant and Boiler; DHW can, optionally or additionally, also be defined at the zone level]

[The curve is automatically rescaled to render given average total usage]

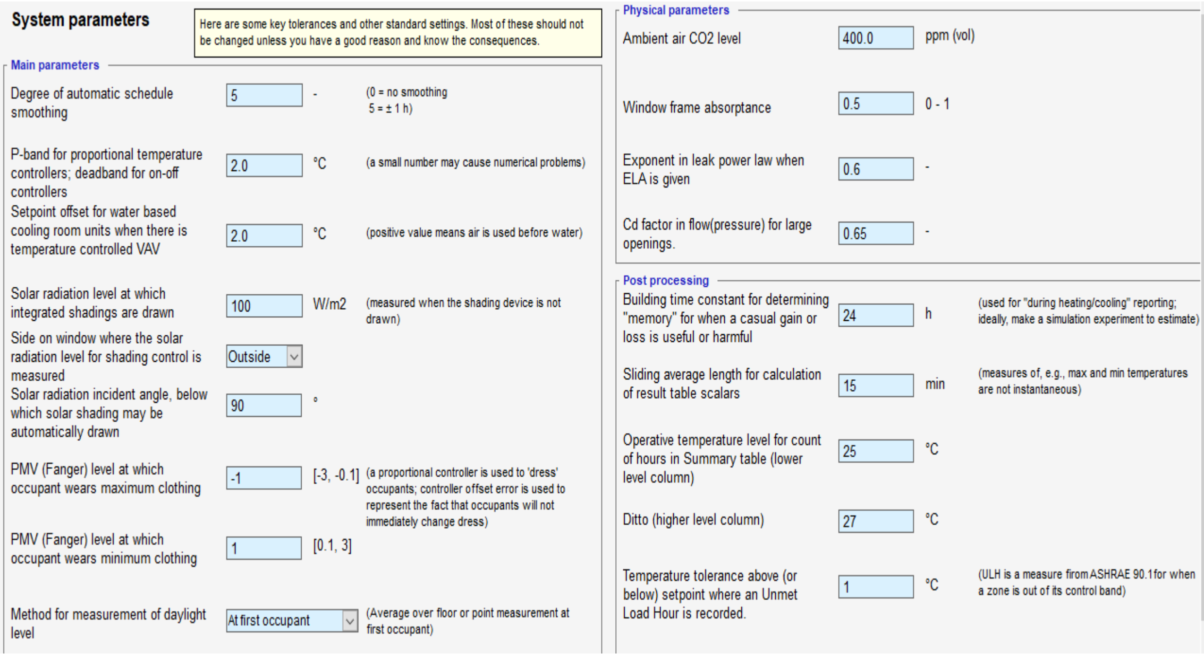
Distribution System Losses

Domestic hot water circuit	0.212	W/(m2 floor area)	50	% to zones*
Heat to zones	2.0	% of heat delivered by plant (incl. delivered to ideal heaters)	50	% to zones*
Cold to zones	0.0	W/m2 floor area	50	% to zones*
Supply air duct losses	0.08	W/m2 floor area, at dT_duct_to_zone 7 °C	50	% to zones*

[*Share of loss deposited in zones according to floor area]

Figure 27: extra energy lost during the supply and connections.

There are also other parameters that are also discussed in the process of simulation.



System parameters

Here are some key tolerances and other standard settings. Most of these should not be changed unless you have a good reason and know the consequences.

Main parameters

Degree of automatic schedule smoothing	5	-	(0 = no smoothing 5 = ± 1 h)
P-band for proportional temperature controllers; deadband for on-off controllers	2.0	°C	(a small number may cause numerical problems)
Setpoint offset for water based cooling room units when there is temperature controlled VAV	2.0	°C	(positive value means air is used before water)
Solar radiation level at which integrated shadings are drawn	100	W/m2	(measured when the shading device is not drawn)
Side on window where the solar radiation level for shading control is measured	Outside		
Solar radiation incident angle, below which solar shading may be automatically drawn	90	°	
PMV (Fanger) level at which occupant wears maximum clothing	-1	[-3, -0.1]	(a proportional controller is used to 'dress' occupants; controller offset error is used to represent the fact that occupants will not immediately change dress)
PMV (Fanger) level at which occupant wears minimum clothing	1	[0.1, 3]	
Method for measurement of daylight level	At first occupant		(Average over floor or point measurement at first occupant)

Physical parameters

Ambient air CO2 level	400.0	ppm (vol)
Window frame absorptance	0.5	0 - 1
Exponent in leak power law when ELA is given	0.6	-
Cd factor in flow(pressure) for large openings.	0.65	-

Post processing

Building time constant for determining "memory" for when a casual gain or loss is useful or harmful	24	h	(used for "during heating/cooling" reporting; ideally, make a simulation experiment to estimate)
Sliding average length for calculation of result table scalars	15	min	(measures of, e.g., max and min temperatures are not instantaneous)
Operative temperature level for count of hours in Summary table (lower level column)	25	°C	
Ditto (higher level column)	27	°C	
Temperature tolerance above (or below) setpoint where an Unmet Load Hour is recorded.	1	°C	(ULH is a measure firom ASHRAE 90.1for when a zone is out of its control band)

Figure 28: System Parameters in IDA ICE.

5 Simulation and Calculation

So, it is a yearly simulation.

After giving all the necessary input data and making a complete identical model which can be seen in figure 29 and then simulation took place where we include solar panels for electricity as well as for thermal energy. There is also a heat pump included in the work along with a wind turbine. And the results are shown in table 7.

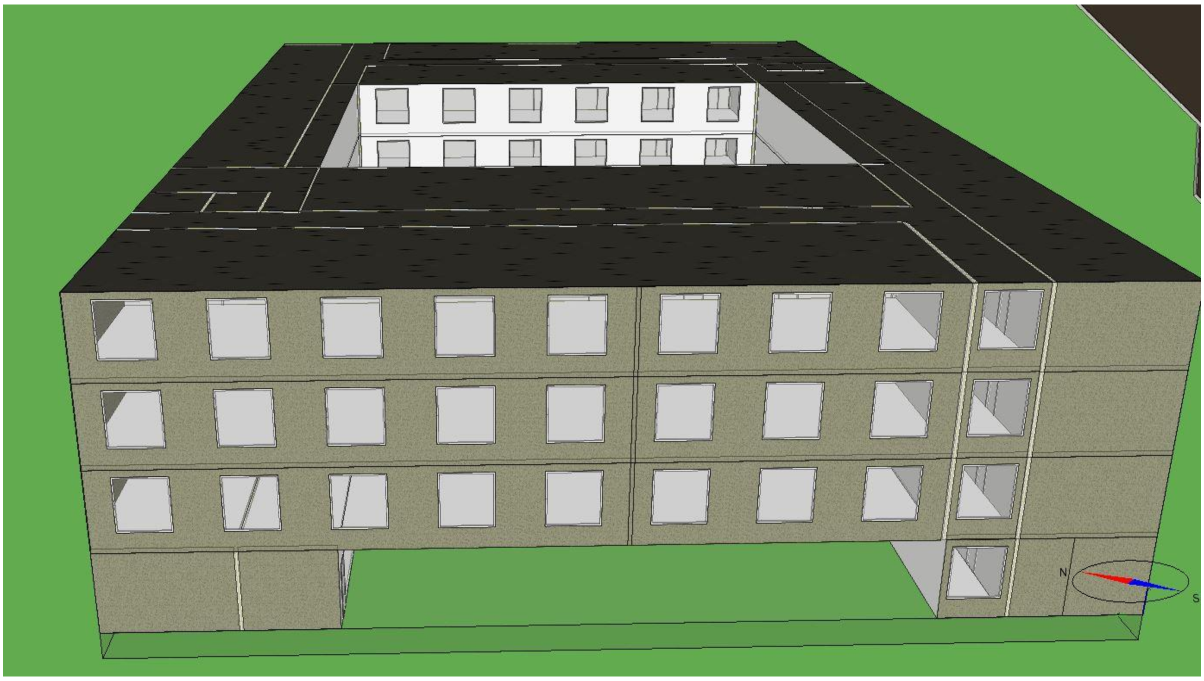
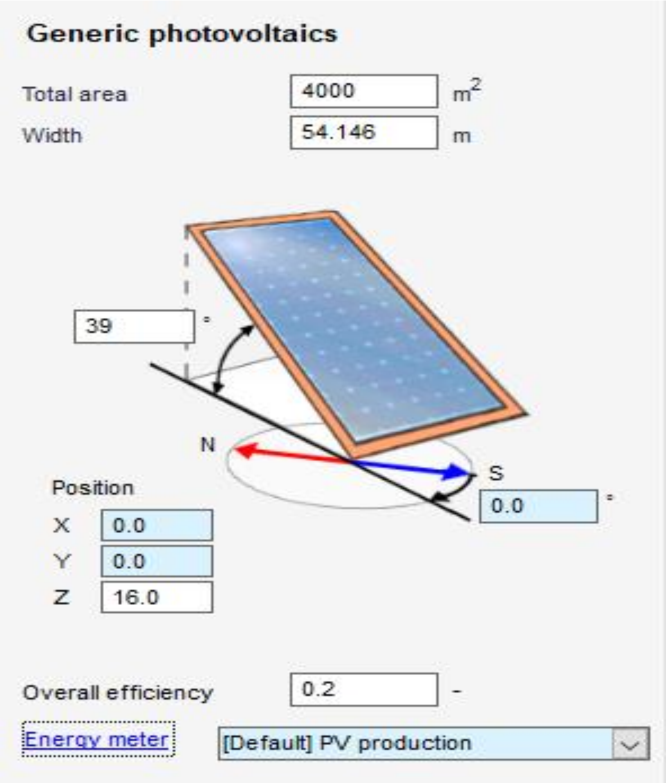


Figure 29: A 3D model of the building in IDA ICE.

The building is oriented in such a way so that the bigger portion of the building is exposed to solar radiation. And the roof is quite big, so we assumed that the solar panel was installed on the roof and in the parking area. The total area for the solar PV taken is 4000m^2. We can see the orientation of the solar panels in figure 30 below. As we can see it is a generic photovoltaic panel with an efficiency of 20 % arranger at an angle of 39^o for the better solar radiation facing.



Generic photovoltaics

Total area: 4000 m^2

Width: 54.146 m

39 °

Position

X: 0.0

Y: 0.0

Z: 16.0

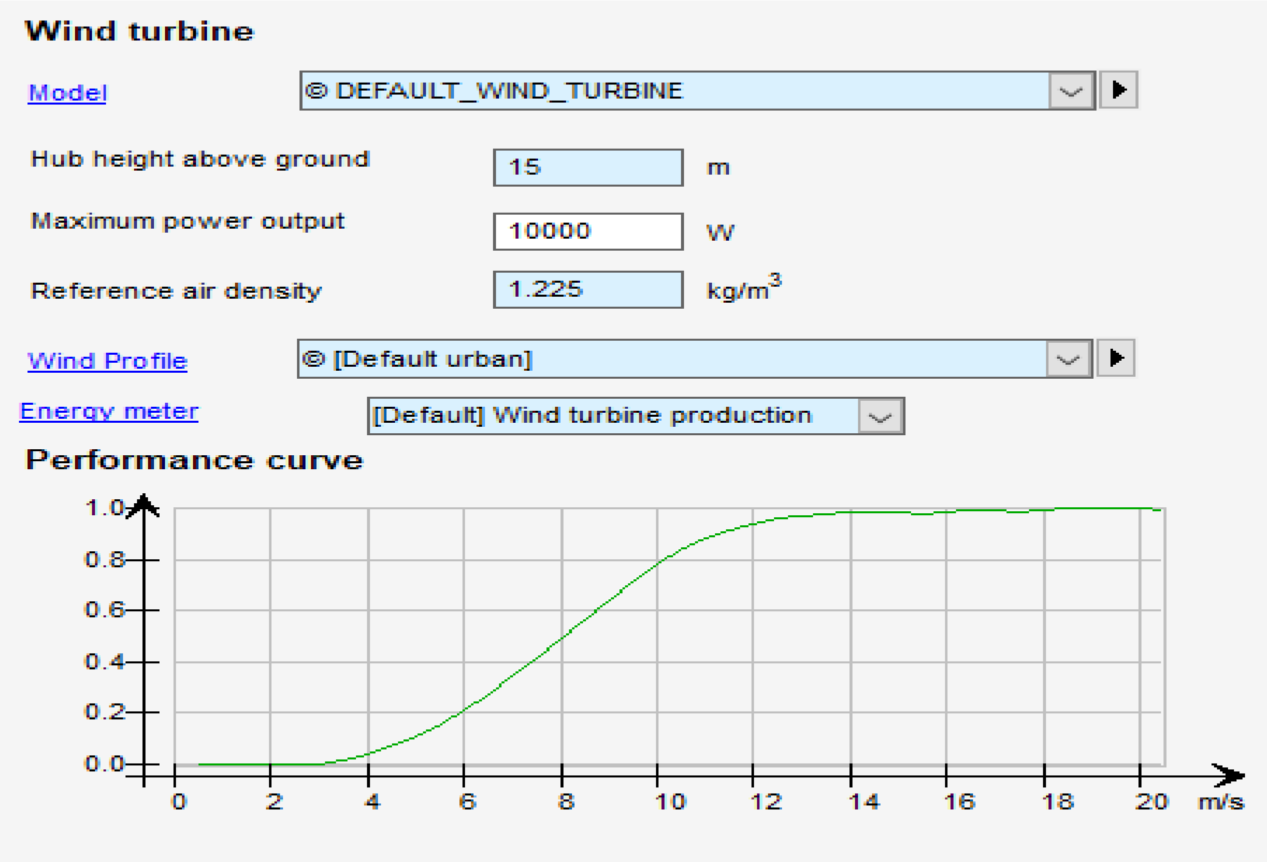
0.0 °

Overall efficiency: 0.2 -

Energy meter: [Default] PV production

Figure 30:arrangement of solar PV.

For the wind turbine we can take any corner of the dorm as it has a very big premises.



Wind turbine

Model: © DEFAULT_WIND_TURBINE

Hub height above ground: 15 m

Maximum power output: 10000 W

Reference air density: 1.225 kg/m^3

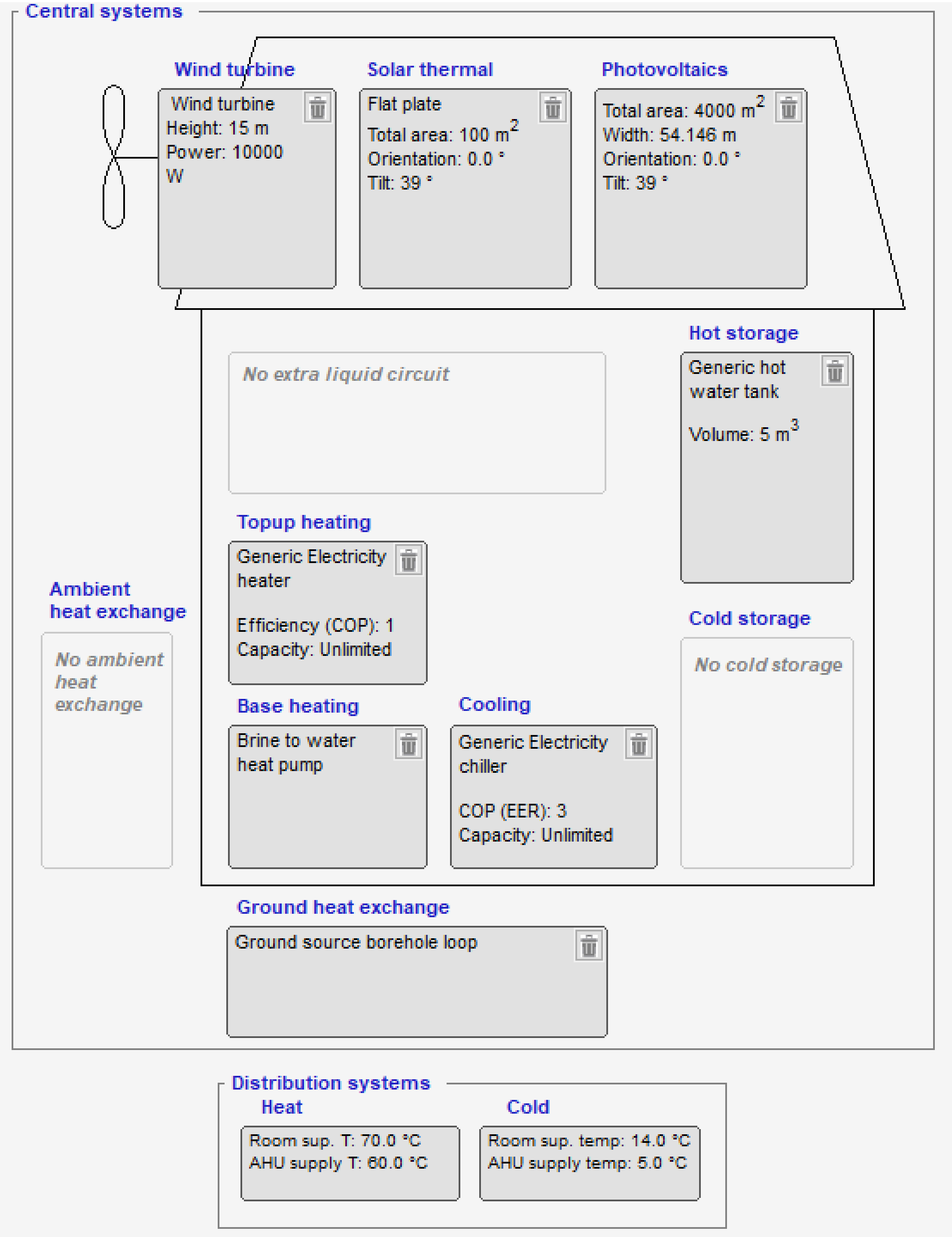
Wind Profile: © [Default urban]

Energy meter: [Default] Wind turbine production

Performance curve

Figure 31: Wind turbine properties with performance curve.

This whole renewable arrangement is done in an inbuilt model. We can see this arrangement in figure 32.



Wind turbine
Height: 15 m
Power: 10000 W

Flat plate
Total area: 100 m^2
Orientation: 0.0 °
Tilt: 39 °

Total area: 4000 m^2
Width: 54.146 m
Orientation: 0.0 °
Tilt: 39 °

No extra liquid circuit

Generic hot water tank
Volume: 5 m^3

Generic Electricity heater
Efficiency (COP): 1
Capacity: Unlimited

No ambient heat exchange

No cold storage

Brine to water heat pump

Generic Electricity chiller
COP (EER): 3
Capacity: Unlimited

Ground source borehole loop

Room sup. T: 70.0 °C
AHU supply T: 60.0 °C

Room sup. temp: 14.0 °C
AHU supply temp: 5.0 °C

Figure 32: Renewable plant arrangement.

If we talk about heat pump, then these are the parameters that came into experience during the year.

Table 8: Parameters of a Heat pump.

COP	5.16 – 5.5
Brine massflow [kg/s]	0.63 – 0.59
Condenser masssflow [kg/s]	0.298
Compressor power [W]	1988.3 – 1903.2
Condenser power [W]	11162 – 10486
Evaporator power [W]	9173 – 8582.9
Condensation temp. [deg C]	20.2 – 19.283
Evaporation temp. [deg C]	-11.924 - -13.889
Entering brine temp. [deg C]	-0.34 - -2.91
Temperature to tank [deg C]	14.997 – 14.303
Leaving brine temp. [deg C]	-4.616 - -7.148

Table 9: Demand of the energy required within the building in model1 and model2.

Meter	Model 1 [kWh]	Model 2 [kWh]
Lighting, facility	13223.1	4424.1
Electric cooling	6101.9	5725.7
HVAC aux	103115	102425
Electric heating	450519	435294
Heat pump heating	177456	108899
Equipment, tenant	82365	81604
PV production	490219	521710
Wind turbine production	119	128.8
Total	342442	216533

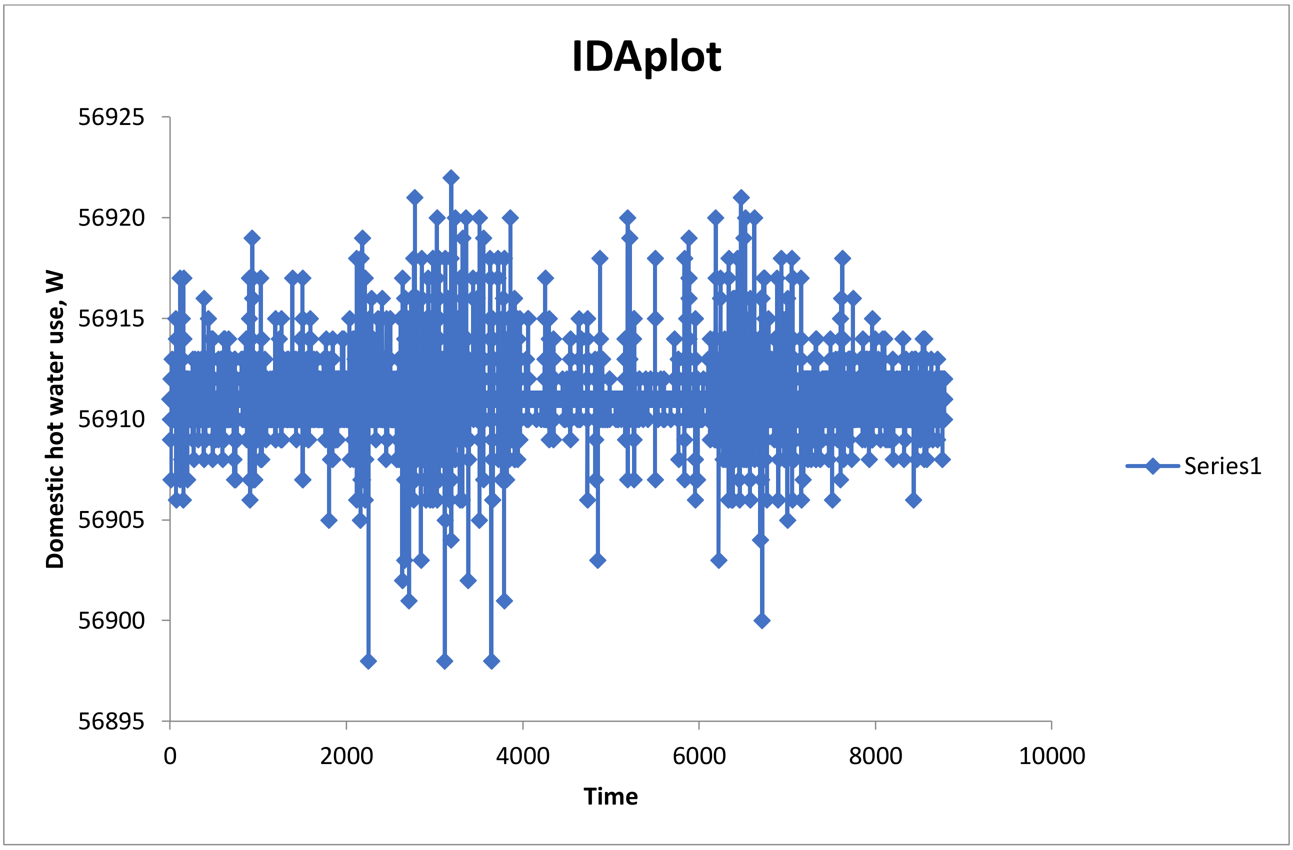


Figure 33: Domestic hot water use in Watt vs Time (hour)

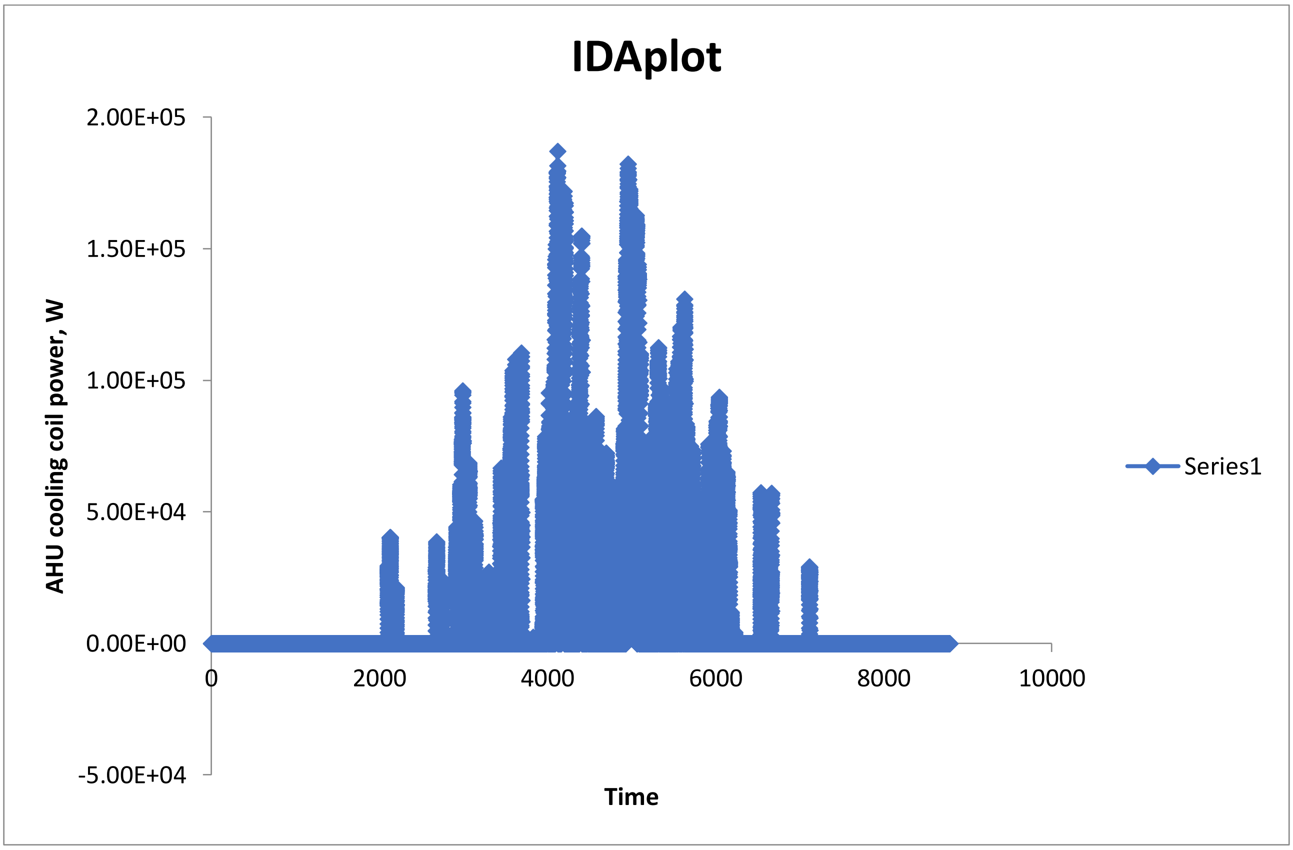


Figure 34:Air Handling Unit cooling coil power in watt vs time(hour).

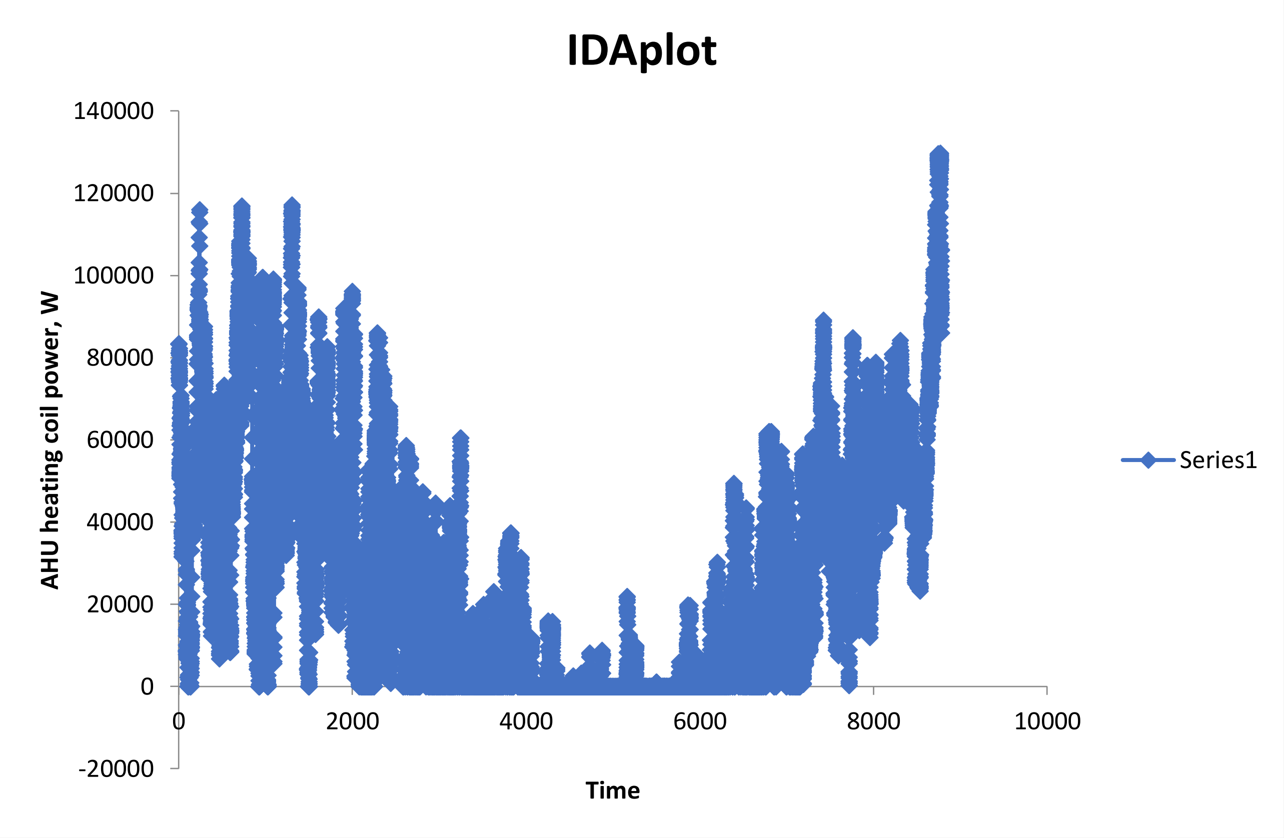


Figure 35: Air handling unit heating power in watt vs time in hours.

Model1:

With the initial data needed the lighting units to utilize 13223.2 kWh of electricity whereas cooling, heating, and HVAC combined utilized 737191.9 kWh of energy. This is the energy that is being consumed by the building and now we also have PV production and wind production which collectively produce 490338 kWh of energy.

So total energy consumed is 832780 and energy produced by renewables is 490338.

If we calculate the overall energy consumed by the building, then it is 342442 kWh.

So, we produced around 58.88% of the overall energy by renewables.

So, on that 58.88% of the energy, the CO2 emission is zero if we do not consider the initial emission of PV and turbine. The CO2 emission in Germany for producing one kWh of electricity can be 401gram [14] as projected.

And on the other side out of 41.22% of energy, 40% of it is from renewable sources as discussed by Fraunhofer Institute. This means 60% of 342442 produce around 82391.55 g of CO_2 perh. This whole calculation is a yearly calculation.

Where in model 2 the major change takes place in the lighting and facility energy consumption. It is because initially their light bulb with 100W and later in mode2, it is 10W. So, in model2 the total energy consumption by the whole building is 738371.8kWh. And the renewables produced 521839kWh. So, we required an additional 216533kWh of energy from the grid. Out of which 40% is renewable so in total buildings consume 129919.8kWh of energy from non-renewable sources, which is only 17% of the total energy required so we can say that only this much of energy is the only reason for emission, the building is responsible for. So, the total carbon emissions, in this case, are 52097.84 g.

6 Conclusion

The thesis aims to calculate the energy use in the building and the amount of CO2 production and how to make it nearly zero building. I created a replica model of the currently existed Student dorm building.

The basic initial building dimension is taken from the drawing available on the premises. The orientation of the building is observed and then decided by the Google Maps services. The input value of the model-like material used in the building is all selected from the database.

The model is focused on energy consumption and at the end, there is also the calculation of CO2 emission happen due to electricity production and overall building performance.

Both the models showed a few changes after simulation, the only big change was in the lighting unit of the facility. Even after so much effort the real-time data of the building is not available. But still, the simulated data and calculation showed significant energy production by renewables and lower carbon emissions.

After conducting this work, creating an energy model for a building is a challenging task and needs a lot of effort to achieve valid and reasonable results. This model only determines the closest energy demand of the buildings only.

After conducting the simulation and modeling the model still need to be improved and there is a lot of scope for improvement.

Even in the simulation, the results need to be improved by introducing some energy-efficient equipment. In the end, Germany is putting its efforts to improve the building design and building material so that the energy demand can be reduced, and they can achieve near-zero energy buildings and this can only be possible by good energy simulation models and their implementation.

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