Reducing energy usage in multi-family housing

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Abstract. The energy usage in residential sector have been around 22% of the total energy use in the world and increasing due to the population growth and higher living standards. The energy sources for this are made up primarily of non-renewable energy resources which generates a large amount of global greenhouse gases. A lot of countries have implemented various regulations and rules to reduce the energy usage in buildings and promoting the use of renewable energy technologies. This paper presents a parametric study of a typical multi-family building in its pre-design stage. The climate location used is Sweden (Gothenburg) and Japan (Osaka). The aim of the study is to compare various configurations and to examine how they affect the energy use. The most interesting configurations are the use of heat pump and solar cells. Other configurations that are examined are infiltration levels, pressure coefficients, wind impact, ventilation with heat recovery, ventilation scheduling, building orientation and finally changing U-values in the building material. Results of this study show that the energy saving, by utilizing a heat pump and solar panels, can reduce the total energy use by 34.9% for Gothenburg and 32% for Osaka. The results also show that the difference in total energy use between the two cities reduce substantially (3% difference) when utilizing a heat pump in combination with solar panels.

1. Introduction

The energy usage in residential buildings have been around 22% of the total energy use in the world for 2016 and increasing due to the population growth and higher living standards. The energy sources for this are made up primarily of non-renewable energy resources which generates a large amount of global greenhouse gases. Although there have been an increase in several renewable energy sources such as wind and solar power, they are only covering a small portion of the world energy demand which is dominated by fossil fuels [1]. A recent report from the UN Intergovernmental Panel on Climate Change (IPCC) indicates that the carbon pollution have to be cut by 45% by 2030 compared to previous targets for limiting global warming to 1.5°C [2]. The European Union has already implemented regulations and rules to promote the use of renewable energy in buildings and this will further intensify if more reports come out that shows that we have less time to stop and reverse the climate change [3]. The rapid increase in cutting carbon pollution requires change in thinking when designing new buildings.

One of the tools that are used to evaluate the energy usage in buildings is building performance simulation (BPS) software. With BPS software one can predict and evaluate the various aspects of a buildings. BPS software are mainly used in the pre-design stages of a building or when carrying out a retrofit for an existing building [4-6]. Another area they are used in are for case studies such as this paper. There have been numerous studies carried out with the help of BPS software [7-10]. The primary use of BPS software in those studies have been to evaluate energy demand, heating load and thermal comfort. The energy usage in a building is dependent on many factors that interact which each
In this study a typical multi-family building (regarding Sweden standards) in its pre-design stage is evaluated based on the following factors:

- Site geographical location, orientation and climate file
- Wind profile
- Infiltration
- Pressure coefficients
- Ventilations system
  - AHU with supply and exhaust (includes heat recovery)
  - Return air only (with no heat recovery)
- Heating delivery system (HDS)
  - Electricity only
  - Ideal heat pump
- Electricity from solar panels
- Building material

The aim of this study is to evaluate what parameter, or a combination of parameters, have the highest influence on energy performance of the building in Gothenburg (Sweden) and Osaka (Japan). The BPS software that is used in this study is Indoor Climate and Energy (IDA ICE) 4.8 which is a dynamic simulation software that supports multiple zones to evaluate energy usage, energy loads and thermal comfort. This can be done for room level or for the entire building [12, 13]. The accuracy of the software has been investigated and shown good correlation against real measurements [14]. Another study made by Travesi J et al. (2001), who examined the accuracy of the software, carried out an empirical validation study related to the thermal performance of buildings and the results showed good agreement between the measured data and the simulated cases [15]. In 2001 IDA ICE was validated according to European Strandard prEN 13791 [14].

2. Method

2.1. Baseline model

![3D view and floorplan overview of the building.](image)

Figure 1. 3D view and floorplan overview of the building.

At start, a baseline model was created based on a building drawing obtained from plans for a future building construction in the city of Gothenburg. Next, parameters were implemented according to Swedish standards for inputs such as lighting, equipment, number of occupants, hot water consumption, temperature setpoints and U-values for building materials [16-18]. A 3D-layout as well as a floor plan of the building is showed in Figure 1. The building has three floors in total. The ground
floor is planned to host two small businesses, while the 2nd and 3rd floor are used for apartments. The layout for 2nd and 3rd floor is identical. In total, there are 2 areas reserved for small businesses (Zone 1 & 3) and 6 areas are reserved for apartments (Zone 4-6, 8 and 10-11). Zone 2, 7 & 9 are reserved for stairwell. The U-values for the building components are shown in Table 1.

**Table 1. U-values of building construction parts.**

| U-values for building components | U-value [W/(m²K)] |
|---------------------------------|-------------------|
| External walls                  | 0.18              |
| External roof                   | 0.13              |
| External floor                  | 0.15              |
| Windows                         | 1.19              |
| External doors                  | 1.09              |

The climate locations chosen are Sweden (Gothenburg) and Japan (Osaka). These climate files are obtained from ASHRAE [19]. The lighting and equipment for the apartment zones are set to 2000 kWh/year + 800 kWh/occupant/year and for the small business zones it is set to 180.7 kWh/m² and year. 70% of this energy is utilized as internal heat gain. The lighting and equipment scheduling are the same as occupancy for all the zones. The number of occupants in the apartments, the clothing and the schedules are set according to Table 2 and the activity level is set to 1.0 MET.

**Table 2. Number of occupants, clothing and schedules times**

| Zone                          | Clothing (CLO) | Number of occupants | Schedule          |
|-------------------------------|----------------|---------------------|-------------------|
| Zone 3 & 11 (1 room and kitchen) | 0.75 ±0.25    | 1.42                | 17-07 Every day   |
| Zone 5, 6, 8, 10 (2 room and kitchen) | 0.75 ±0.25    | 1.63                | 17-07 Every day   |
| Zone 1 & 3 (local store)       | 0.85 ±0.25    | 5                   | 07-18 Every day   |

**Table 3. Input parameters in IDA ICE baseline model**

| Parameters                                      | Value                           |
|------------------------------------------------|---------------------------------|
| Model volume                                   | 1 826.1 m³                      |
| Model envelope area                            | 990.9 m²                        |
| Window to envelope ratio                       | 6.9%                            |
| Heating set point†                             | 21°C                            |
| Cooling set point†                             | 25°C                            |
| AHU (FTX) heat recovery efficiency†            | 70%                             |
| AHU (FTX) Specific Fan Power (SFP)†            | 1.8 [kW/(m³/s)]                 |
| Average hot water use†                         | 12 534 kWh/year                 |
| Airing energy loss†                            | 2 155 kWh/year                  |
| Infiltration†                                   | 0.6 ACH @ 50 Pa                  |
| Pressure-coefficients†                         | Exposed                         |
| Wind profile†                                   | Ocean (ASHRAE 1993)             |

| Notes                                                                 |
|-----------------------------------------------------------------------|
| † The value is obtained from Swedish building regulation [16]          |
| ‡ The value is obtained from SVEBY guidelines [18]                    |
| § The values is obtained from ASHRAE [19, 20], see also IDA ICE help section for more in depth details |

Other important simulation parameters are presented in Table 3. The total floor area and the volume of the building is 214.6 m² and 1962.0 m³. The floor area of the business zones (1 & 3) are 83.4 m² and
100.2 m$^2$. The floor area of the apartment zones varies between 24.2 m$^2$ and 70.5 m$^2$. The floor area of the stairwell zones is 24.2 m$^2$. The size of the windows are 1.2 x 1.5 m and the external doors 1.2 x 2.0 m. The ceiling height is 3.3 m for the ground floor and 2.6 m for the rest. The heating system is based on electric radiators. There are two air handling units (AHU) for the building, one for the apartment zones and the other for the business zones. All the cooling capacities of the AHU is disabled. There are however separate cooling units in the business zones (1 & 3) which have COP 3. Solar radiation level at which integrated shadings are drawn is set to 100 W/m$^2$.

The ventilation flowrate for the business zones is set to 3.0 l/(s/m$^2$) for supply air and 3.24 l/(s/m$^2$) for exhaust air. For the apartments it is set to 0.35 l/(s/m$^2$) for supply air and 0.38 l/(s/m$^2$) for exhaust air.

### 2.2. Parametric setup

The parametric setup is carried out by making some changes to the baseline model and save this as a specific model [21]. Table 4 shows all the model configurations and what has been changed compared to the baseline model. After the creation of these models a simulation is carried out for all these configurations to evaluate the energy usage of each model. The simulation type is dynamic, and the period of the simulation is one year (normalizing weather data is used).

**Table 4. Model configurations for parametric study in IDA ICE.**

| Parametric model | Change                                      |
|------------------|---------------------------------------------|
| Model 1          | Infiltration – 0.2 ACH @ 50 Pa               |
| Model 2          | Pressure-coefficients – sheltered           |
| Model 3          | Wind profile – suburban (ASHRAE 1993)       |
| Model 4          | AHU – exhaust air only                      |
| Model 5          | AHU – change the scheduling for apartment zones |
| Model 6          | Change orientation by +90 °                 |
| Model 7          | Change the U-value for the building components (higher) |
| Model 8          | Installed solar panels (86 m$^2$ solar panels (30° tilt)) |
| Model 9          | Cooling enabled in all zones                |
| Model 10         | Using an ideal heat pump with COP 3         |
| Model 11         | Using ground heat pump with COP 3 + 86 m$^2$ solar panels (30° tilt) |

In Model 4 both the AHUs are replaced with exhaust air only. In Model 5 the flowrate to the apartments are decreased by 70% between 07-19 (when it’s assumed that the occupants are not at home). In Model 7 the U-values are increased for the external walls (0.24 W/(m$^2$K)), roof (0.17 W/(m$^2$K)) and windows (1.55 W/(m$^2$K)). In Model 8 solar panels are installed on the roof side facing south. The total area of the solar panels is 86 m$^2$, the tilting 30° and the overall efficiency is 15%. In Model 9 the cooling is enabled which makes it possible to remove any access heat during the hot periods. The COP value for the cooling units are 3. In Model 10 an ideal heat pump with a COP 3 is used for the heating system. In Model 11 the solar panels in Model 8 is combined with the heat pump (COP 3) in Model 10.

### 3. Result and discussion

This section is divided into four parts. The first part covers the climate difference between the two cities. The second and third part will cover the total energy use of the baseline model and the parametric models in Osaka and Gothenburg and the fourth will cover the difference between the two cities.

#### 3.1. Climate analysis

Since a comparison is made between two different climate region it’s important to evaluate the difference in weather condition between the two regions. Figure 2 shows the average temperature for both Osaka and Gothenburg over the simulation period. The average temperature in Osaka is higher.
than in Gothenburg which leads to lower heating demand in Osaka. On the other hand, the cooling demand will be higher in Osaka during the warmer periods.

![Figure 2](image_url)

**Figure 2.** Average monthly temperature and diffuse radiation on a horizontal surface for Gothenburg and Osaka.

The graph also shows that the largest temperature difference between the two locations are during the summer time. From this it’s possible to assume that the heating requirement will be higher for Sweden and the cooling requirement will be higher for Japan. Another important aspect is the average diffuse radiation on a horizontal surface which is higher in Osaka during most of the months in the year.

### 3.2. Total energy use for Osaka location

The total energy use in kWh/m² for Osaka is shown in Figure 3. The result shows that Model 1, which was the change in infiltration, has very low impact on the total energy usage in the building. There is a slight reduction in the total energy use, around 0.4%. In Model 2 and 3 a similar pattern is shown; the total energy use is reduced by only 0.4%. In Model 4, which is the change of the AHU to exhaust air only, the total energy usage has increased by 7.6% due to removal of the possibility of heat recovery from the exhaust air. There has been a substantial reduction on the HVAC auxiliary power (47.6%) but that reduction is not enough to offset the increase in heating energy usage. A slight reduction (3.1%) is also noted for the cooling requirement. Model 5 reduces the ventilation requirements for the apartments when the occupants are not present. This generates a reduction of 3.2% in the total energy use. In Model 6 the building is rotated + 90° which means that the windows facing south will face west and the north windows will face east. This change increases the total energy use by 0.7% which is provided primarily by an increase in heating energy use (3.1%). In Model 7 the U-value of several building components are increased which leads to a decrease in the insulation level of the building which in turn leads to an increase in the heating energy use (13.0%) and a small decrease in the cooling. The total energy use is increased by 2.2%. Model 8 introduces solar panels which allows the building to generate its own electricity and a reduction of total energy use by 19.6%. This electricity is distributed throughout the building and covers some part of the electricity requirements of each area. Total electricity production is 16 643 kWh/year. There is also a slight overcapacity (202 kWh/year) during some periods when the electricity can be sold to the grid or stored. In Model 9 cooling units are installed in the apartments. This leads to an increase in the cooling energy use (38.3%) which at the end leads to an increase in the total energy use by 3.5%. In Model 10 an ideal heat pump with COP 3 is replacing the electric heating system which operated at COP 1. This change creates a reduction in
heating energy usage by 66.8% resulting in a total reduction of 12.6%. Finally, a combination of Model 10 and Model 8 is created as Model 11. This configuration takes advantage of both the heat pump and the solar panels. This combination reduces the energy usage across almost all energy sections and results in a total reduction of 32.0% in energy usage and a small electricity overproduction of 455 kWh/year.

![Figure 3. Total energy usage for Osaka baseline and parametric models.](image)

3.3. Total energy use for Gothenburg location
The total energy use in kWh/m² for Gothenburg is shown in Figure 4. The cooling energy usage is very low across all models, between 0.7 and 1.1 kWh/m². Because of these low levels they have not
been highlighted in the figure. Similar to the Osaka simulation, Model 1-3 show minor change in the total energy use, a reduction by 1.6 - 2.0%. In Model 4 the heating energy use increases by 112.3% due to the removal of heat exchanger and no supply air. There is also a 46.8% reduction in HVAC auxiliary energy use. In Model 5 there is a small reduction in the energy use for heating and HVAC auxiliary. In Model 6 a slight increase occurs in the heating energy use. Model 7 creates a higher energy use for heating which leads to a total increase of energy use by 6.1%. In Model 8, the solar panels electricity generation reduces the total energy use by 12.4% with a small overproduction of 129 kWh/year. In Model 9 the enabling of cooling units had almost no effect on the total energy use. In Model 10 the ideal heat pump reduces the heating energy use by almost 2/3 and in Model 11 the combination of heat pump and solar panels creates a total energy reduction by 34.9%.

3.4. Comparison between Osaka and Gothenburg

The major variable that effects the simulation between these two cities is the climate. The results show that cooling energy use is substantially higher in Osaka across all models compared to Gothenburg. In contrast the heating energy use in Gothenburg is almost twice as that of Osaka. In terms of total energy use Gothenburg’s energy use for Baseline model and Model 1-3, 5-6 is between 7.7 and 9.4% higher than Osaka. Interestingly there is a huge difference for Model 4 where Gothenburg requires 33.1% more energy use, the reason being a large increase of heating energy needed due to the loss of heat recovery potential. In Model 7 the difference is 13.5% between the two cities. The lower insulation values have greater impact in a cold climate such as Sweden compared to Japan. In Model 8 the difference increases to 19.2% due to much higher solar radiation levels in Japan compared to Sweden which is utilized by the solar panels. In Model 9 the total energy use in Gothenburg is 5.7% higher than in Osaka. The reason for this is that the cooling requirements are much higher in Osaka. This will decrease the gap in energy use compared to the Baseline model, but Osaka still have a lower total energy use. Surprisingly, the total energy use in Model 10 is 3% lower in Gothenburg compared to Osaka. This is the only model that showed a lower total energy use for Gothenburg. The reason for this is that the cooling units in all models are already set to COP 3. Since the cooling requirement for Osaka is much higher than in Gothenburg there is no change in that section compared to the Baseline model. On the other hand, the heating energy use is reduced by almost 2/3 for both cities but it is more beneficial to Gothenburg since it has twice the amount of energy use for heating compared to Osaka. Finally, in Model 11 the difference tip in favor for Osaka since the electricity generation of the solar panels are higher there than in Gothenburg. Gothenburg have 4.8 % higher total energy use than Osaka. Another interesting aspect is that Model 10 makes the difference between the cities very small in terms of total energy use.

4. Conclusion

The models that had the lowest impact on the total energy use in both cities are 1-3 and 5. The model that reduced the total energy most was 11 which reduced the energy use for Gothenburg and Osaka by 34.9 and 32% respectively. Once a heat pump for heating is installed, the difference in total energy use between the two cities reduce substantially (-3%) despite the large difference in yearly average temperature and solar radiation. It’s also worth mentioning that the heat pump is an ideal one that operates at a constant COP 3 when it is utilized. This also apply for the cooling units.

Nomenclature

| Acronym | Description                      |
|---------|----------------------------------|
| AHU     | Air Handling Unit                |
| BPS     | Building Performance Simulation  |
| COP     | Coefficient of Performance       |
| HDS     | Heating Delivery System          |
| IPCC    | UN Intergovernmental Panel on Climate Change |

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