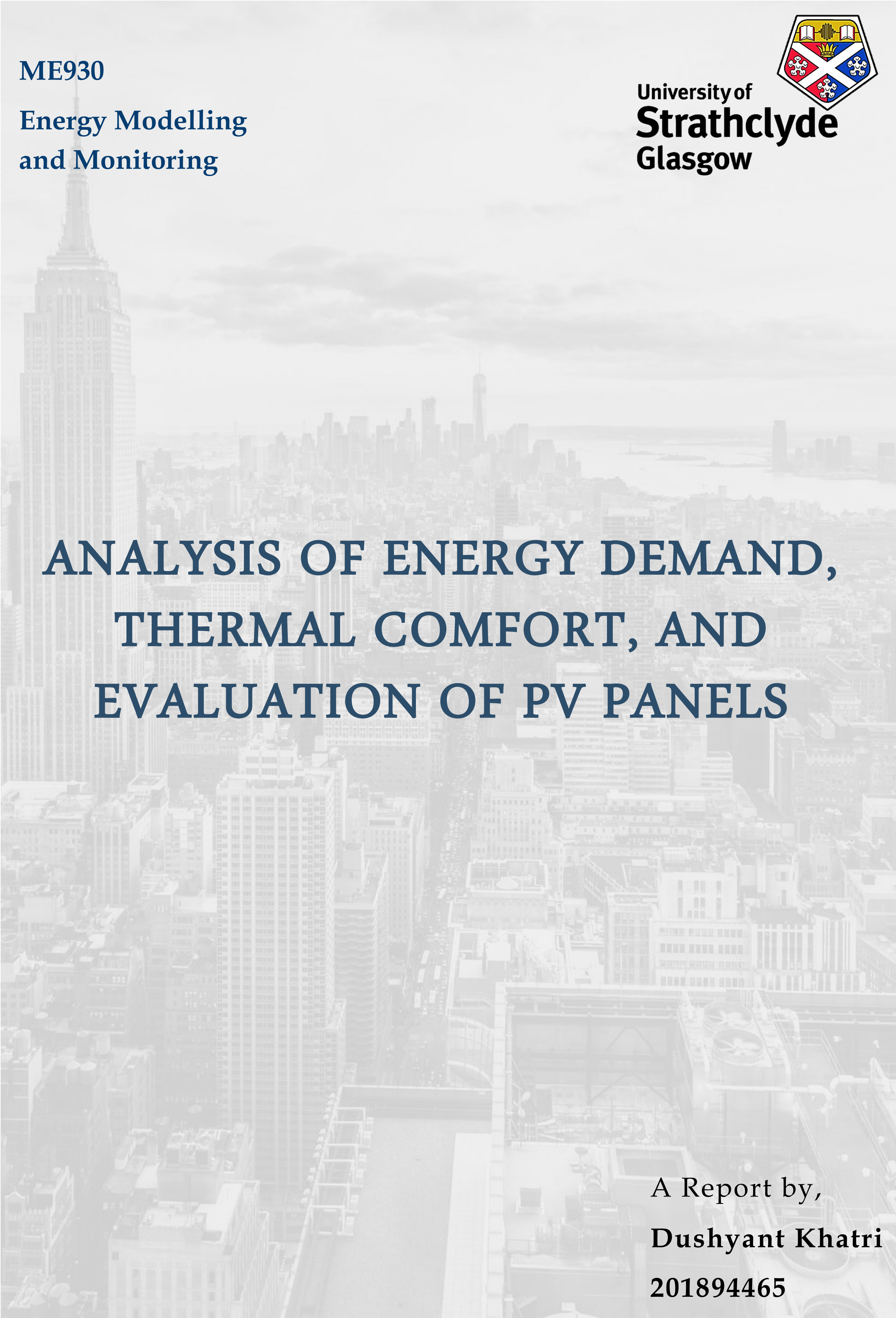

ME930

Energy Modelling and Monitoring

ANALYSIS OF ENERGY DEMAND, THERMAL COMFORT, AND EVALUATION OF PV PANELS

A Report by,

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Introduction

"A good indoor climate is important for the success of any building, not only because it will make its occupants comfortable, but also because it will decide its energy consumption, and thus influences sustainability."

- (Thapa and Panda, 2015)

Thapa and Panda (2015) highlight on how the indoor temperature within a building contributes to its overall energy performance. By this, it could be related to why it is evident that many researchers recognise the significance of improving energy efficiency in buildings (Bataineh and Alrabee, 2018). The European-Commission (2018) indicates that building services account for 40% of the global energy consumption and aims to potentially reducing the EU's energy consumption to 5-6% by renovating existing buildings. All the above statements point out to a common concern of creating innovative solutions to smartly consume and generate energy for buildings. The word 'smart' in this context is implied as intelligently and sensibly consume and generate energy, considering its sustainability factors and long-term benefits.

The key elements in energy analysis of buildings that are of particular interest in this report, are energy demand for heating and cooling, and the level of thermal comfort for occupants. Another aspect of particular interest is adopting the use of PV panels for energy generation.

Parsons (2010) defines thermal comfort as a desirable or a positive state of a person in relation to how warm or cold he feels, which is clearly related to the environment he occupies. He further explains that thermal comfort is important in a way such that it directly affects the psychological state of the occupant, for example, a person's mood and behaviour. It is legitimate to assume that the performance of the occupants in completing their tasks would directly be affected by the thermal comfort of a building.

Although it is required in the report to analyse energy generation by photovoltaic (PV) panels, it is acknowledged that PV panels are sustainable solutions to generate energy whilst reducing the carbon footprint. Kemme and Zeiler (2017) recognise the potential of using PV panels for high-performance (sustainable) buildings by stating that these are becoming considerably popular even in countries such as the Netherlands, where solar radiation is limited. As this being the case, it could be anticipated that PV panels could potentially be used as one of the efficient sustainable tools in buildings energy management.

Description of the model

This report aims to address the energy efficiency task at a preliminary stage. In addition to performing energy analysis and simulations, the report would help in establishing the level of technical understanding in interpreting the generated results and how this relates to the overall energy performance of the building. The problem is described to be a small office building for a medical practice located in Chicago. The model is analysed and results are produced by using a software called ESP-R. Figure 1 gives a visualisation of the model, as generated in ESP-R, in a perspective view and a bird's eye view.

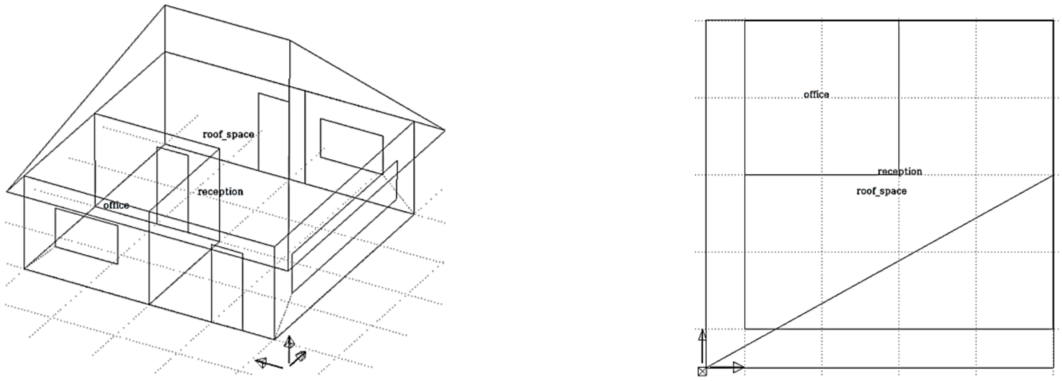

Figure 1 - Visualisation of the model in ESP-R (Perspective view and Bird's eye view)

Objectives

The project consists of two major objectives. For convenience in interpreting the data and classifying them to achieve a clear comprehension of the problems and their corresponding results, the first objective is sub-divided as given below:

1. **<u>First Objective</u>** – Analysing the proposed design and,
   1.1. Evaluating the energy demand for heating and cooling considering the current design
   1.2. Evaluating the level of thermal comfort provided by the current design
   1.3. Proposing changes to improve performance. Performance (here) can be defined as achieving a better thermal comfort level and appreciably reducing the energy demand.
2. **<u>Second Objective</u>** – Analysing on Renewable Energy Supply
   This involves evaluating the amount of energy that would be generated, should PV panels be installed on the roof of the proposed design.

Assumptions

As the objectives (scope) of the report are clearly outlined, it is important to indicate the assumptions at this stage, as indicated below:

1. It is assumed that ESP-R is an efficient software in performing the analyses to achieving the objectives.
2. It is assumed that the exemplar models are not faulty, and are considered to be accurate for the completion of the report.
3. As the available climate data is for the year 2001, it is assumed that the design and analysis for energy performance is conducted in 2001. Also, it is assumed that the data is accurate.

Numerical Analyses and Simulations performed

The list of numerical analyses and simulations performed directly relate to the objectives of the report as given below:

We open the existing file with an option in ESP-R Project Manager called 'Open Existing', where we select the desired file. In order to achieving the first objective, which is fairly straight-forward, we perform the simulation by clicking on Browse/Edit/Simulate→ Simulation→ Integrated Simulation→ Run Silently. Once the simulation is completed, clicking on 'Result Analysis' would open further options in a separate window to explore different attributes of generated results in a graphical or tabular format.

Heating and cooling within the building annually

In analysing the indoor temperature within the building, the period is set from the 1st of January 2001 until the 31st of December. In the 'Result Analysis' window, we select Enquire about→ Energy Delivered→ Reception and Office. This achieves the objective 1.1, where we evaluate the energy demand for heating and cooling considering the current design. Although the objective is fulfilled, we go on further to comprehend the indoor temperature in a typical summer week and a typical winter week.

Indoor temperature in a typical summer week

When specifically considering a typical summer week, say in this case from the 1st of July 2001 until the 7th, the energy demand can be achieved by changing the time period by selecting 'Display Period'.

Indoor temperature in a typical winter week

Similar to what was considered as a typical summer week, defining a typical winter week, say from the 21st of January 2001 until the 27th, would provide an output of the energy demand within the building; this is further elaborated in the 'Results' section, further in this report.

Thermal comfort

The thermal comfort was analysed by selecting 'comfort metrics', and graphically representing the Predicted Mean Vote and the percentage of occupants dissatisfied with the thermal comfort by the current design for a 52-week (one year) period. To define the comfort parameter, we select clothing level as 0.7, activity level units as MET, activity level as 1.546 (defined by default), air velocity as 0.1, and casual gains as occupants. This achieves the objective 1.2.

Evaluation of energy generated by installing PV panels on the roof of the building

As a part of this evaluation, it is important to install a PV panel initially in one of the rooftop walls. Selecting the south-side wall, *s_roof*, we add the required construction by referencing one of the other previously defined exemplar models using the PV panels. The sequence is defined in Table 1.

Table 1 - Sequence in order which the south-side roof wall is defined

Layer	Thickness (mm)	Material
1	3.00	Low-Iron-Glass
2	3.00	EVA layer
3	3.00	Low-Iron-Glass
4	20.00	Gap
5	12.00	Roofing felt
6	50.00	Light mix concrete
7	50.00	Gap
8	8.00	Ceiling (plaster)

Further, running the simulation as defined for the Heating and cooling within the building annually, we obtain the temperature inside the roof. Again, as the model is inspired by another exemplar model, the electrical networks are defined for this model by considering the existing model of similar characteristics.

The results expected would fulfil the objective 2 of the report. One of the particular aspects is the energy generation. The results are graphically represent the energy generated over a period of one year, with records generated on an hourly basis. This means that the x-axis would have units as hours and the y-axis (energy generated) would have units as kWh.

Results

Heating and cooling within the building annually

Although the result could be achieved by graphical representation over a 12-month period, presenting the results in a tabular form is easier to interpret. From Table 2, it can be interpreted that whilst heating is delivered for a certain number of hours in a year, there is no cooling delivered within the building at any point over the year. It can be observed that the office consumes more than double the amount of energy, whilst nearly three times the number of hours when the heating is used.

Table 2 - Results tabulated for heating and cooling of the building annually

	Sensible Heating		Sensible Cooling	
	Energy (kWh)	No. of hours	Energy (kWh)	No. of hours
Reception	245.35	594	0	0
Office	558.56	1539	0	0
Total	803.9	2133	0	0

Indoor temperature in a typical summer week

Table 3 - Results tabulated for heating and cooling over a typical summer week

	Sensible Heating		Sensible Cooling	
	Energy (kWh)	No. of hours	Energy (kWh)	No. of hours
Reception	0	0	0	0
Office	0	0	0	0

It can be observed from Table 3 that there is no heating and cooling during a typical summer week. It is legitimate to state that during the summer, it is logical not to use any heating considering the climate in Chicago (described in Appendices). However, it could be suggested that the cooling be used over the summer, as not using cooling may affect the thermal comfort within the building.

Indoor temperature in a typical winter week

Table 4 - Results tabulated for heating and cooling over a typical winter week

	Sensible Heating		Sensible Cooling	
	Energy (kWh)	No. of hours	Energy (kWh)	No. of hours
Reception	11.5	29	0	0
Office	27.68	60	0	0
Total	39.2	89	0	0

It is apparent from Table 4 that there is no cooling required during a typical winter week, and therefore, there is no cooling provided. Although, there is a significant amount of heating provided. Again, it can be noticed that the office consumes more than double the amount of energy and slightly more than double the amount on the number of hours than the reception.

Thermal comfort

Predicted Mean Vote (PMV)

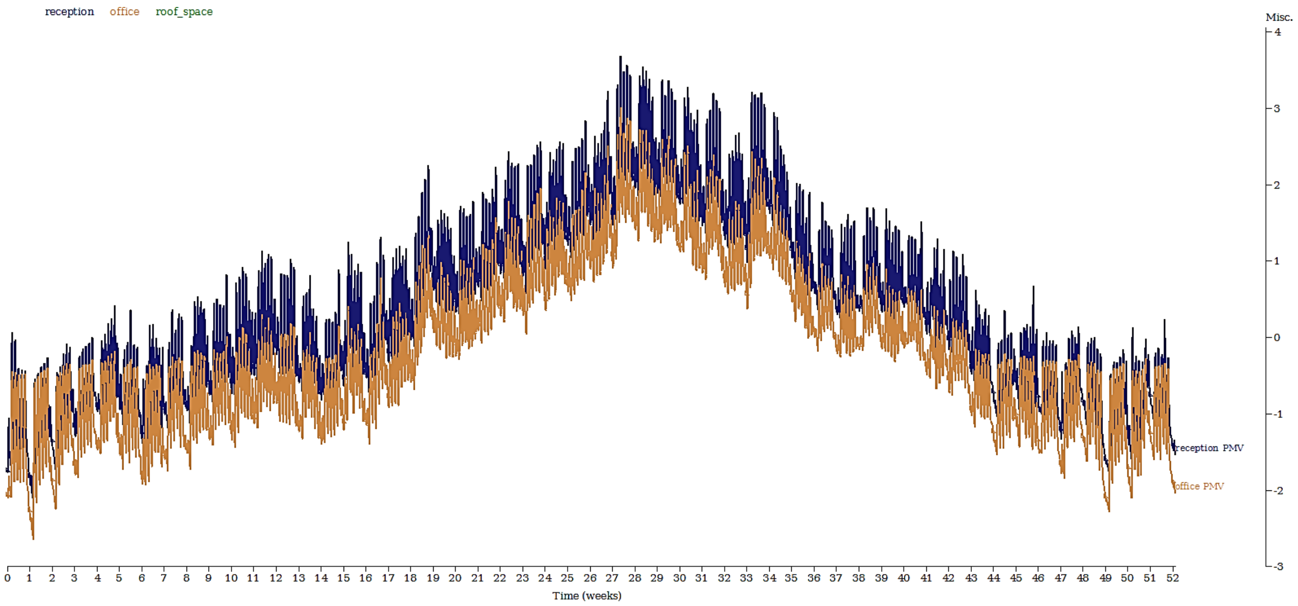

Figure 2 - Graphical representation of PMV over the year, as generated by ESP-R

As interpreted from Figure 2, the peak PMV is from week 27 until week 34, approximately through the summer weeks of the year. PMV is defined as the measure of thermal comfort, and are directly related to the comfort parameters mentioned when performing the simulation ; A positive PMV denotes the intensity of warmth, and a negative PMV denotes the intensity of coldness (Han *et al.*, 2014).

Percentage Dissatisfied (PPD)

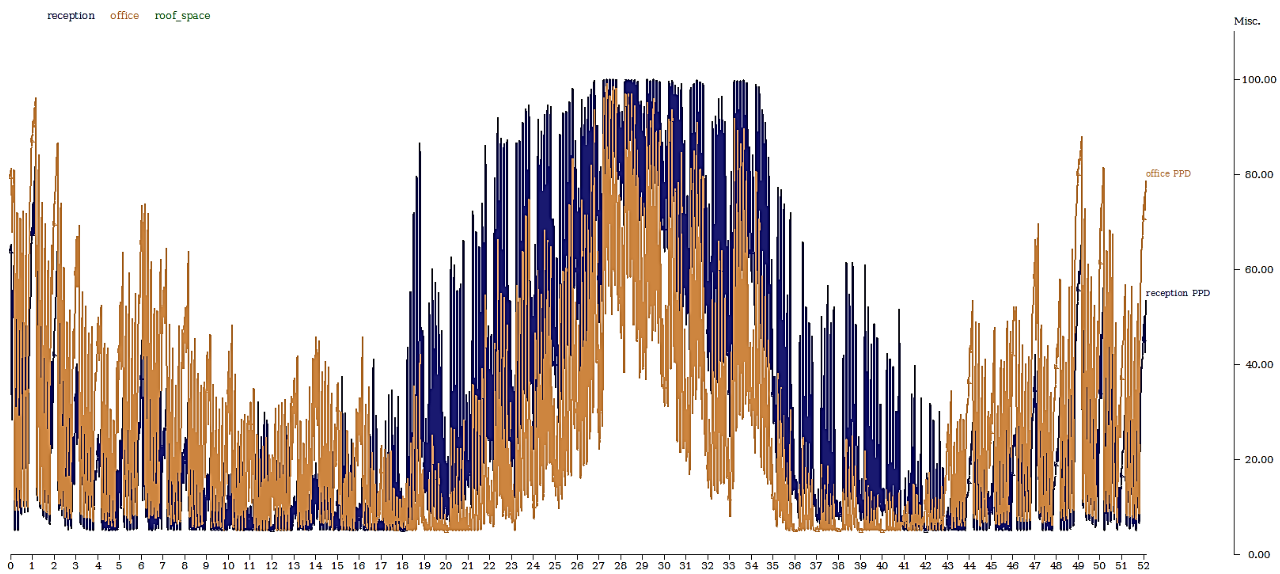

Figure 3 – Graphical representation of PPD over the year, as generated by ESP-R

It can be interpreted from Figure 3 that the peak PPD is attained over the summer weeks. It is evident that during this period (week 23 to 35), the PPD drastically rises. A significant rise is also observed for the office space between weeks 0 to 4 and weeks 47 to 52, which approximately denotes the winter period.

Proposed changes in improving the current design

The results generated for the energy demands and thermal comfort are taken into consideration, along with the material and construction attributes of the building that significantly influence the ambient temperature within the building (Costola, 2018). Definitions of these attributes are given in Appendices.

Improving thermal comfort: From the results generated on energy demand and thermal comfort, it is evident that there is a higher level of dissatisfaction among occupants at the Reception and the Office during certain climatic changes. Obtaining energy demands specifically over a typical summer week confirms that with no cooling and the warm ambient temperature (given in Appendices), it is highly likely that the occupants would experience a level of discomfort. Therefore, it can be proposed to introduce cooling on warm days.

Appreciably reducing the energy demand: Another factor which could be noticed is that despite the office area covers a smaller area (lesser occupants) of the building, it consumes more than double the energy than the reception. Should the heating be monitored for the office in an efficient manner, the overall energy consumption over the year would result in a significant reduction. Therefore, it can be proposed to monitor the heating for the office to an appropriate setting. In addition to this, changing the material and construction of walls that are pre-defined can also lead to a better thermal comfort.

Conclusion

In regards to the first objectives, it is analysed that the current design did not efficiently fulfil the energy consumption required by the building. As a result, the thermal comfort achieved was not satisfactory. This was evidenced by the high percentage of PPD. To fulfil the objective 1.3, proposing improvements on the current design included introducing cooling within the building to regulate the indoor temperature during warm days. It was also acknowledged that the energy consumption for the office was more than double than what was consumed for the reception, although the office was a smaller space than the reception. In this regard, it was proposed that the heating should be monitored such that the overall energy consumption is achieved when the energy consumption is reduced for the office.

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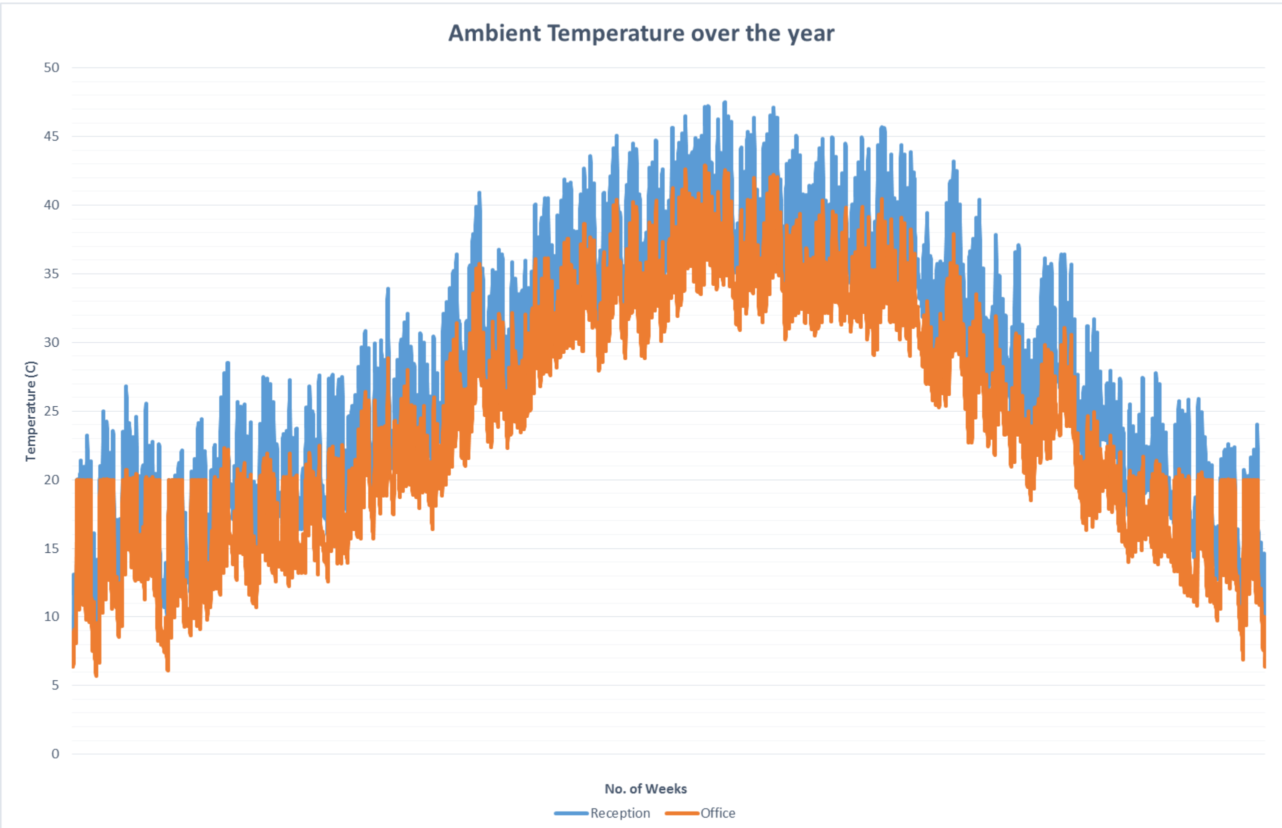
Appendices

Appendix A - Definitions

- Opaque – A material which is not translucent.
- Emissivity – Effectiveness of a surface in emitting energy such as thermal radiation.
- Absorptivity – The property of the body that determines the fraction of the absorbed incident radiation.
- Conductivity - The degree to which a specified material conducts electricity, calculated as the ratio of the current density in the material to the electric field which causes the flow of current.
- Specific heat - The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius.

Appendix B – Ambient Temperature

The ambient temperature refers to the temperature within the enclosed system, in this case, the small office building used for medical practice in Chicago. The climate of Chicago was evaluated and so was the ambient temperature of the building. The graph generated is as follows:



It can be observed that the ambient temperature reaches to 48 ^{o}C during the summer at the Reception, and up to 43 ^{o}C at the Office, whilst the temperature goes down up to 5 ^{o}C in the winter.