T.C.
SAKARYA UNIVERSITY
INSTITUTE OF SCIENCE AND TECHNOLOGY

BUILDING ENERGY MANAGEMENT SYSTEM DESIGN BY USING INTERNET OF THINGS

Ph.D. THESIS

Haithem CHAOUCH

Department	**:**	**ELECTRICAL AND ELECTRONICS ENGINEERING**
Field of Science	**:**	**ELECTRONICS**
Supervisor	**:**	**Prof. Dr. Celal ÇEKEN**

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This thesis has been accepted unanimously by the examination committee on 05.08.2021

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DECLERATION

I declare that all the data in this thesis was obtained by myself in academic rules, all visual and written information and results were presented in accordance with academic and ethical rules, there is no distortion in the presented data, in case of utilizing other people’s works they were refereed properly to scientific norms, the data presented in this thesis has not been used in any other thesis in this university or in any other university

Haithem CHAOUCH

05.08.2021

PREFACE

I would like to express gratitude and thank to “ALLAH” for his favors. I was unable to arrive at this achievement without his bless and help.

Secondly, I would like to expand my respect to my supervisor Prof. Dr. Celal Çeken for his incredible efforts and advice. Also, I would like to extend my thanks to YTB (Yurtdışı Türkler ve Akraba Topluluklar Başkanlığı) for giving me this opportunity to continue my PhD thesis research at Sakarya University. And I might want to thank all my colleges and collaborators in the Internet of Things laboratory and all people in the institute were very helpful.

Finally, I would like to extend my special gratitude to my family for their support, trust, prayers, love, and endless patience.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	: Air Conditioners
ASHRAE	: American Society of Heating, Refrigerating and Air Conditioning Engineers
BMS	: Building Management System
COA	: Center Of Area
EPW	: Energy Plus Weather
FL	: Fuzzy Logic
HVAC	: Heating, Ventilation, and Air Conditioning
IoT	: Internet of Things
IR	: Infra-Red
ISO	: International Standards Organization
JSON	: JavaScript Object Notation
LED	: Light Emitting Diode
M2M	: Machine to Machine
PWM	: Pulse Width Modulation
RF	: Radio Frequency
RP	: Raspberry
Wi-Fi	: Wireless Fidelity
TO	: Output Temperature
TOSi	: Indoor ambient Temperature of Open Space
TN	: Neighbours ambient Temperature
NTOSi	: New setpoint Temperature of Open Space

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SUMMARY

Keywords: IoT; M2M; Fuzzy Logic, Smart Building; Energy Management System; Smart air Conditioning, Embedded System, and HVAC.

Over the last few decades, the energy consumed by appliances is increasing year by year during peak hours due to the level of comfort of occupants in the smart building. Right now, this issue is one of the most important researches in the world. Several studies propose some solutions in order to solve some problems. One of them is to save energy during peak hours and others focus on the management and control of HVAC (Heating, ventilating and air conditioning) and lighting systems.

The main advantage of integrating building management and control system in building is to ensure comfort, security and energy efficiency for occupants. Our design emphasis on this advantage by using a new standard, such as M2M (Machine to Machine) communication system in the building (Smart Building) and an intelligent control in order to avoid the peak of energy demand while keeping the occupants in their preferred comfort zone by:

- Scheduling of all electrical HVAC equipment and lighting system in SMART BUILDINGs.
- Designing an advanced embedded system for energy management and operation of M2M communication based on ZigBee network.
- Thermal performance of an office building by using different strategies.
- New light control system concept.

NESNELERİN İNTERNETİYLE BİNA ENERJİ YÖNETİM SİSTEMİ TASARIMI

ÖZET

Anahtar Kelimeler: İnterneti, Radyo Frekanslı Tanımlama, ve Bina Enerji.

Bina Enerji Yönetim Sitemleri (BEYS) binalar içerisindeki ısıtma, havalandırma, iklimlendirme ve ışıklandırma sistemlerinin optimum enerji tüketimi yapmalarını temin etmek üzere denetlenmesini amaçlarlar. Bu öneride gerçekleştirilmesi düşünülen sistem ile nesnelerin interneti, Yazılım Tanımlı Ağ ve Makine Öğrenimi yaklaşımları kullanılarak enerji tüketimini mümkün olan en az seviyeye indirmeyi sağlayan bir Bina Enerji Yönetim Sisteminin geliştirilmesi düşünülmektedir.
Önerilen sistem ile iki temel hedefe ulaşılması beklenmektedir.

- Bina içerisindeki odalar istenen konfor düzeyine mümkün olan en kısa sürede ve en az enerji tüketimiyle getirilecektir.
- Bina Enerji Yönetim Sistemi gerçekleştirilirken, Neslerin İnterneti ve Yazılım Tanımlı Ağ yaklaşımlarından faydalanılarak, birimler arasındaki haberleşme sisteminin enerji tüketim oranının azaltılması, güvenlik denetimlerinin kolaylaştırılması, ağ kurulum ve konfigürasyon karmaşıklığının azaltılarak öçeklenebilir tasarım seçeneklerine olanak verilmesi sağlanacaktır.

Bu hedeflere ulaşmak için:

- ANSI/ASHRAE 55 standardına göre kullanıcı konfor düzeyleri belirlenecektir.
- Kullanıcı tercihlerine göre ortamın istenen konfor düzeyine en az enerji harcanarak getirilmesine olanak sağlayacak bulanık mantık algoritmaları içeren merkezi denetim sistemi geliştirilecektir.
- Ortamın konfor düzeyini algılayarak karar destek sistemine gönderen ve ortamı istenen konfor düzeyine getirmek için gerekli denetim işaretlerini ilgili eyleyicilere ileten Yazılım Tanımlı Ağ destekli Nesnelerin İnterneti (Makineden Makineye, M2M) yaklaşımını kullanan yeni bir haberleşme sistemi geliştirilecektir.

CHAPTER 1. INTRODUCTION

This chapter presents an introduction to topics that are covered in the thesis. A problem statement will specify the main issue this research is trying to tackle. The chapter continues to state the aim of this study and the contributions to achieve research goals. Furthermore, a number of related studies are presented then the organization of this thesis is outlined at the end of this chapter.

1.1. Problem Statement And Motivation

Office buildings present an important load of energy consumption in all countries [1] This overload is essentially due to the excessive use of HVAC systems. The ambient temperature in the atmosphere has augmented (1.0^{o}C to 3.7^{o}C) in the last years as a result of the over consumption of the office building.[2] Based on “International Energy consumption Outlook,”[3] the energy consumption of the European countries is more than 100 KWh/m^2 per year for HVAC and lighting systems.[4] Preserving energy become an important task because buildings cover 20% of the total energy consumption of the European countries. Beside of that, the thermal comfort of the user could be impacted by saving energy, accordingly, the productivity of the users in office buildings.[5] Boyce et al. [6] and Rashid et al.[7] indicate that saving energy by assigning some adequate solutions reduce the comfort level of users. Saving energy could put down workers dealing with difficult tasks,[8] in that, accomplishing an adequate balance between comfort and energy is a tough task. The main goal of this dissertation is to overcome these problems and find a new real solution to save the energy.

1.2. Contribution Of This Dissertation

There are three important contributions in this dissertation can be summarized as follows:

- New prototype applied to two air conditioners using Zigbee network and IoT.
- Save energy of an HVAC system by using four control strategies without affecting the thermal comfort of users.
- A new Lighting control system design.

1.3. Related Work

Konis [9] exposed a study that attain an excellent level of energy-saving by saving energy of lighting, and Heating, ventilation, and air conditioning system.

Zeiler et al. [10] take the temperature of the occupants by using infrared sensor implemented on the office desk. As a result, energy saving attain 20% for heating and 40% for cooling while keeping the occupant in their comfortable zone.

Valančius et al. [11] demonstrate that by applying an adequate range of setpoint to the HVAC system (21.6°C to 18°C) could save the energy without decreasing the comfort level of the occupants.

Ari et al. [12] formulate a methodology for providing a satisfactory thermal environment to all occupants (referring to ASHARE standard) of a building while avoiding increased energy consumption. Their methodology based on gradient-based and fuzzy logic control system. The results demonstrated that the solution can provide 28% energy savings.

Authors in [13] focuses on day-lighting to improve the experience of occupant in term of visual comfort by an automatic slat angle control.

Another researcher present a new concept where the building light source is adjusted based on the brightness level of the sunlight [14].

In Ref. [15], new virtual model has been developed by applying different scenarios. The most interesting ones are economy versus comfort mode; fluorescent versus LED lighting; and dimming versus switching lighting control.

Another work proposes hybrid system (Lighting and Climate) based on wireless sensor and actuator network in order to supervise the occupancy of users, temperate, humidity, air velocity, CO2, and luminance levels. Those parameters help the system to save energy and reduce costs by using fuzzy logic control as well as to take into account the office work scheduling [16].

In Ref. [17], a new system is proposed based on low power wireless control like ZigBee network. The system controls the LED light by using PWM signal generated by complementary sensors and Zigbee radio; an implementation of smart LED lighting system including multiple energy-efficient methods without affecting the visual comfort of occupant.

In Ref. [18] a fuzzy logic controller was implemented taking into consideration lighting comfort, daylight, and movement information. The system allows occupants to determine and modify the lighting preference.

1.4. Dissertation Overview

The rest of this dissertation is organized as follows :

- In Chapter 2, present the proof of concept of new prototype using Zigbee network and IoT in order to demonstrate its feasibility and its practical potential.
- Chapter 3, present the implementation details of the proposed building design for analyzing, and validation.

- After the explanation of the utilized building model, a variety of control strategies based on Enabling/Disabling HVAC system, M2M, and Fuzzy logic are interpreted and analyzed in chapter 4.
- In Chapter 5, an efficient system design of light control based on Fuzzy logic system in order to save the energy consumption without affecting the user comfort.
- The dissertation is concluded in chapter 6.

CHAPTER 2. PROOF OF CONCEPT STUDY OF THE NEW HVAC SYSTEM

This chapter presents a proof of concept study to demonstrate that the new HVAC system concept is feasible so we can move further along research and implementation strategies.

2.1. The Proposed Solution

2.1.1. Architecture design

The proposed energy management system based on three parts; first, sensors "Temperature (T) and Humidity (H)" as an input data, second, control and check the system remotely over the cloud system, and third, depending on the environment conditions and the predefined priority of the system the setting of the air conditioner change automatically like fan speed level, Heating/Cooling mode, and setpoint (temperature) as illustrated in Figure 2.1. The proposed controller use different components in order to get autonomous system over Zigbee Network and infra-red controller device to monitor the air conditioner (AC) as depicted in Figure 2.2.

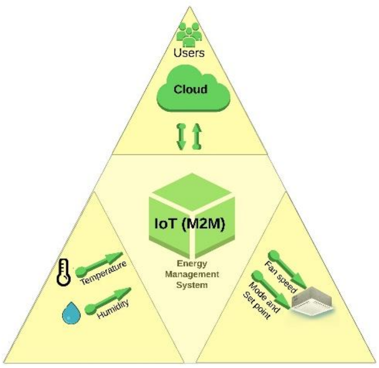


Figure 2.1. Proposed system

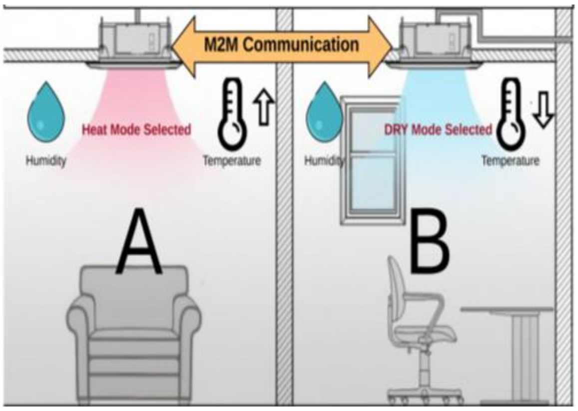


Figure 2.2. M2M communication between two AC

2.1.2. M2M communication

The proposed architecture based on M2M communication through ZigBee device to manage data transfer task. ZigBee network has lower energy consumption and support different type of connection. The solution has been applied on many applications like smart grid, smart city, and smart office building. The collected data from all sensors formatted using an effective standard for packaging task like JavaScript object notation (JSON).

2.1.3. Scheduling algorithm

Our solution based on the following scheduling algorithm in order to implement it as shown in Figure 2.3. over three steps:

- Mode check of air conditioner.
- Monitor the state of each AC (ON/OFF).
- Control the fan speed level of the air conditioner using fuzzy logic controller.

The energy management system observe in real time the ambient temperature of each side in order to give the permission to shift to the heating mode (Controller of the air conditioner) based on some conditions as follow:

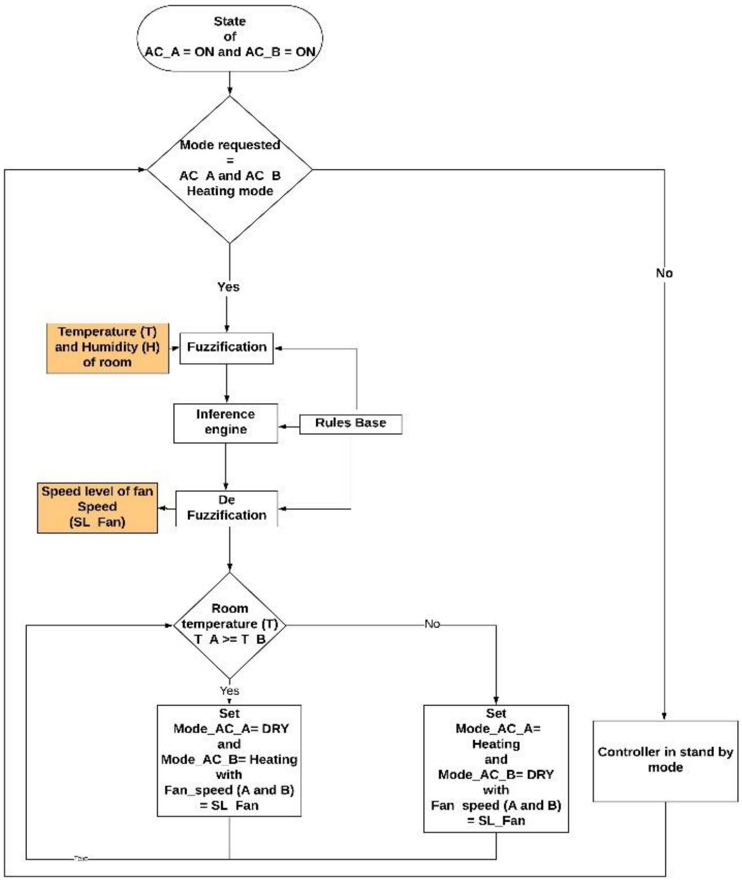


Figure 2.3. Flowchart of the management system

Rules of the fuzzy logic are defined as follow (Table 2.1.):

Table 2.1. Rules of fuzzy logic control

Number of Rule	Temperature	Humidity	Fan Speed
1	N	VW	F
2	H	VD	M
3	H	D	F
4	H	H	F
5	H	W	F
6	H	VW	F
7	VH	VD	F
8	VH	D	VF
9	VH	H	VF
10	VH	W	VF
11	VH	VW	VF

N: Normal, H: Hot, VH: Very Hot, W:Wet, VW: Very Wet, H: Humid, D: Dry, VD: Very Dry, F: Fast, M: Medium, VF: Very Fast

2.2. Implementation And Validation

2.2.1. Implementation

The embedded side is based on two parts as depicted in (Figure 2.4.):

- Gateway: Raspberry Pi3 (1) (Used as a communication point between the cloud center and the controller of energy management system).
- Controller of energy management system (Waspmote (2) controller: Handle ZigBee network; Arduino controller (3): Send the adequate settings to the air conditioner over infra-red signal (6) based on the temperature and the humidity sensor (5); Xbee (4) module: Handle the M2M communication).

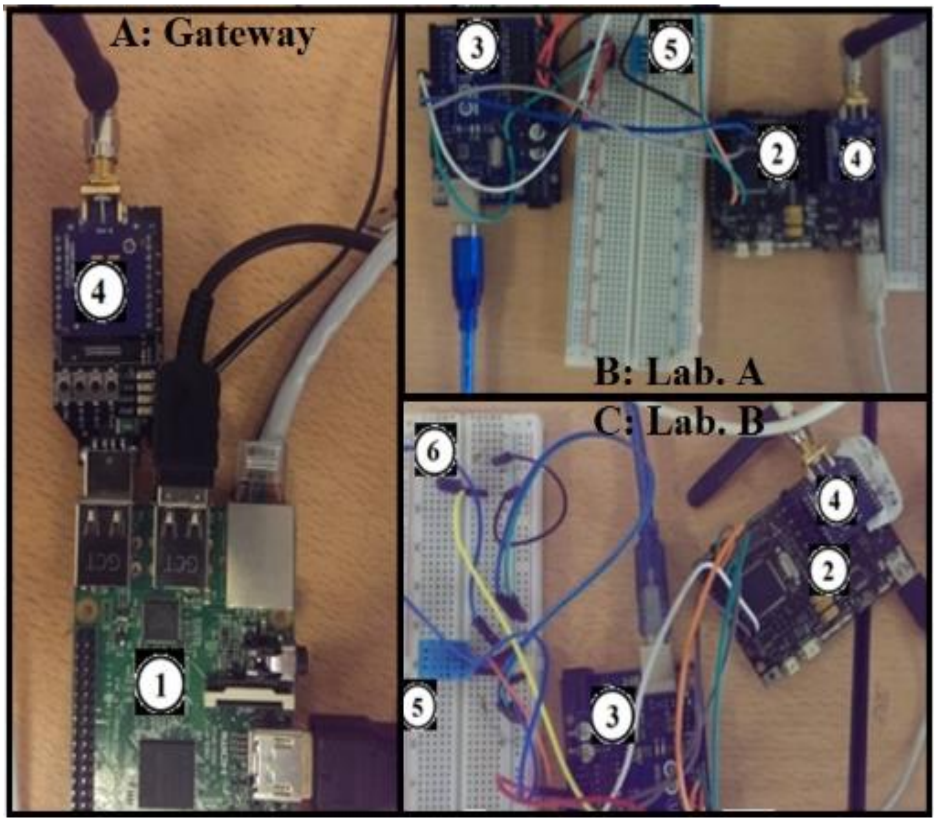


Figure 2.4. The proposed prototype

In order to clarify the mechanism of M2M communication, we illustrate all tasks of the system in the following sequence diagram as depicted in Figure 2.5.:

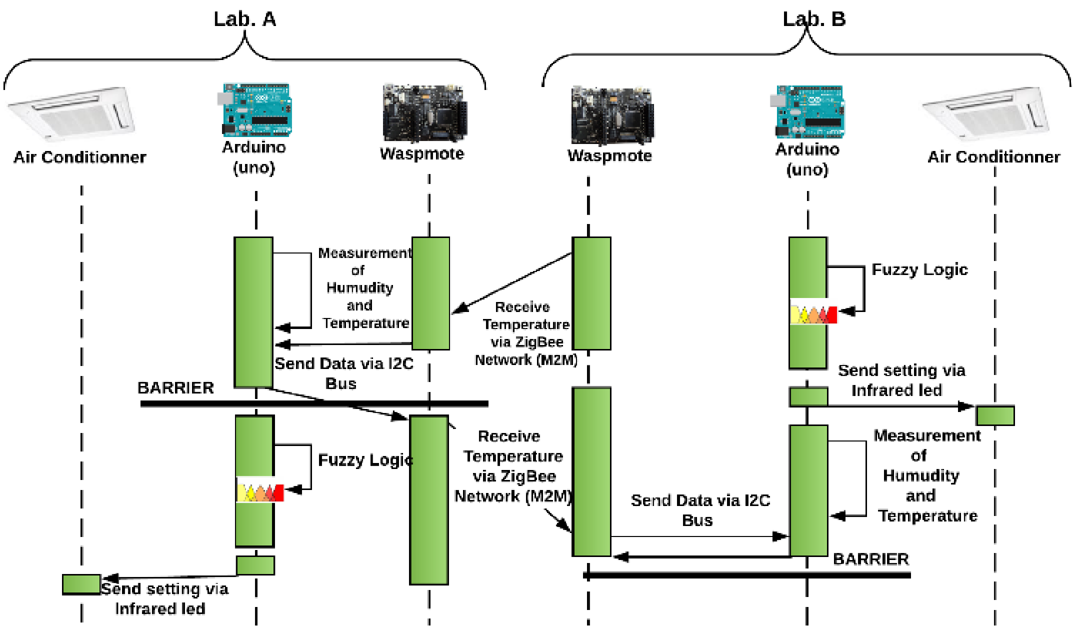


Figure 2.5. Sequence diagram of M2M communication

The proposed system are operated and synchronized using barrier for each side (Laboratory A and Laboratory B). The fuzzy logic system calculate the adequate speed level and send it to Waspmote through I2C port.

2.2.2. Validation

Our proposed solution could be validated by embedding it on real scenario using two air conditioners in two laboratories. The user could define the propre settings (Limit of ambient temperature and limit of power consumption) of the management system using our web application.

2.2.2.1. Measurements test without M2M communication

Over this experiment test we monitor the air-conditioner started with predefined test case for laboratory A and laboratory B. The results of the experiment are depicted in Figure 2.6. and Figure 2.8.

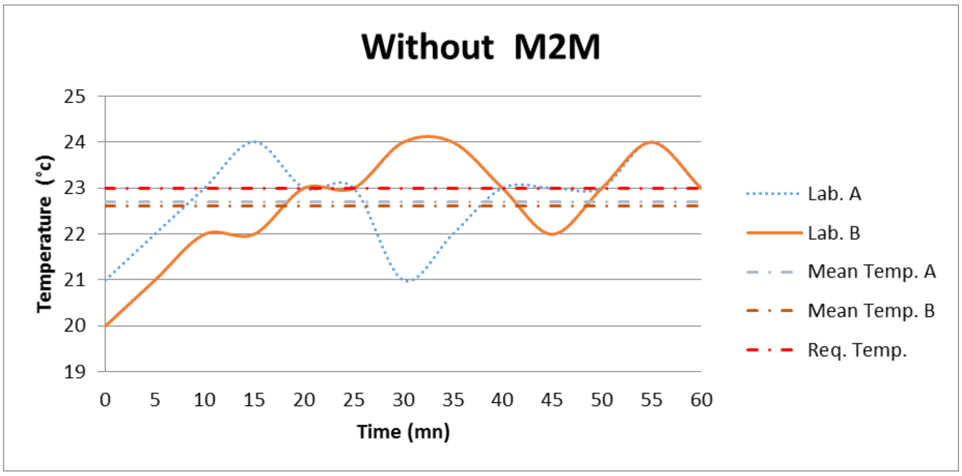


Figure 2.6. Ambient Temperature of Lab. A and Lab. B (Without M2M)

The controller of the air conditioner decide to set the HEAT mode when the ambient temperature drop under the setpoint value (by one degree) as depicted in Figure 2.6.

2.2.2.2. Measurements test with M2M communication

The measurement test with M2M communication take into account the same initial conditions of the previous test. The results of the experiment test with M2M communication are depicted in Figure 2.7. and Figure 2.8.

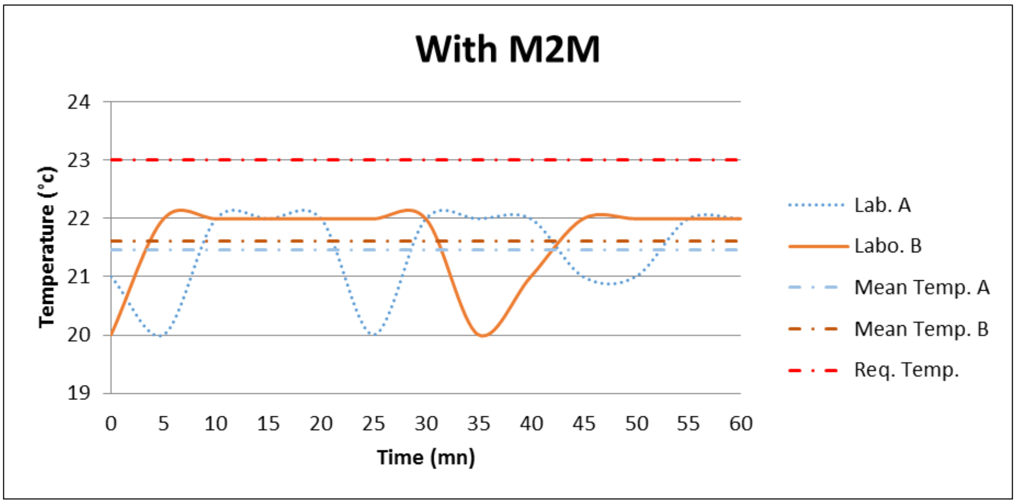


Figure 2.7. Ambient Temperature of Lab. A and Lab. B (With M2M)

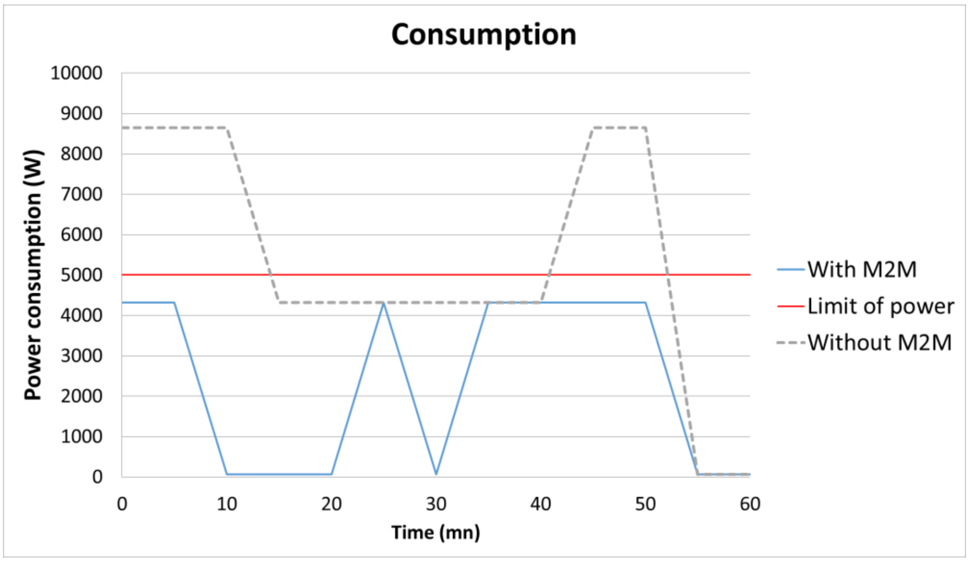


Figure 2.8. Total power consumption of air conditioners with/without M2M

By using M2M communication, the air-conditioner is capable to reduce the energy consumption. However, in the case of without M2M communication the air-conditioner present over power consumption (User limit 5000 W) as presented in Figure 2.8.

2.3. Conclusion

Energy management system based on M2M communication and fuzzy logic system are presented in this chapter. The proposed solution has been implemented to give an efficient energy consumption. According to the results, the proposed solution provide an auto-control system to save energy without affecting the comfort of the occupants. These results motivate us to move further along research and implementation different strategies.

CHAPTER 3. BUILDING MODEL

This chapter introduces a new model of building as follows: The methodology used for the 3D design, the characteristic of the building architecture, and the parameter of the thermal resistance.

3.1. Methodology

Based on the large research on the different tools available, it was clear that a bunch of tools and useful software necessary to develop our first methodology. The selection was focused on how practical and pertinent of these technologies to validate our goals and provide pertinent results. The chosen tools that allowed us to continue in this research are listed below.

3.1.1. Rhinoceros 3D

Figure 3.1. Rhinoceros 3D

Rhinoceros 3D is a modelling software package which allows to design shapes and form surfaces in 3D space. It's an excellent software with a multitude of complex 3D modelling tools, which allow the designer to create form with high precision and detail. Rhinoceros is compatible with most design, drafting, prototyping programs. It was the first used tools to design and develop our smart office building [19].

3.1.2. Grasshopper

Figure 3.2. Grasshopper tools for Rhinoceros

Grasshopper is a programming language executed with Rhinoceros, it was used in the build of algorithms that create the behaviour and of the many design feature. Its environment was also used in different plugins and tools that supported the design space in which the designer could provide his methodology and the arguments that support the research [20].

3.1.3. Ladybug tools

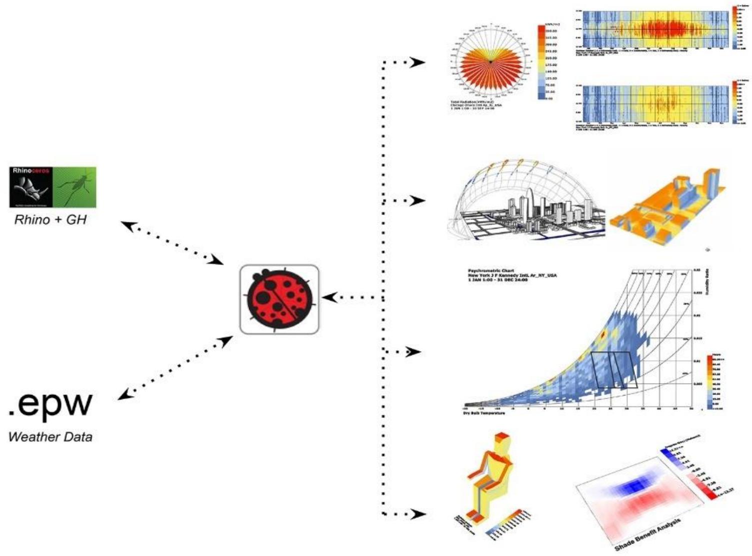


Figure 3.3. Ladybug tools for Rhinoceros

Ladybug tools merge environmental design with a robust toolset for simulation. It allows to use weather data file like EPW file to grasshopper to validate complex simulations. It was used to validate the design solutions based on real weather data with different case scenario [21].

3.1.4. Honeybee tools

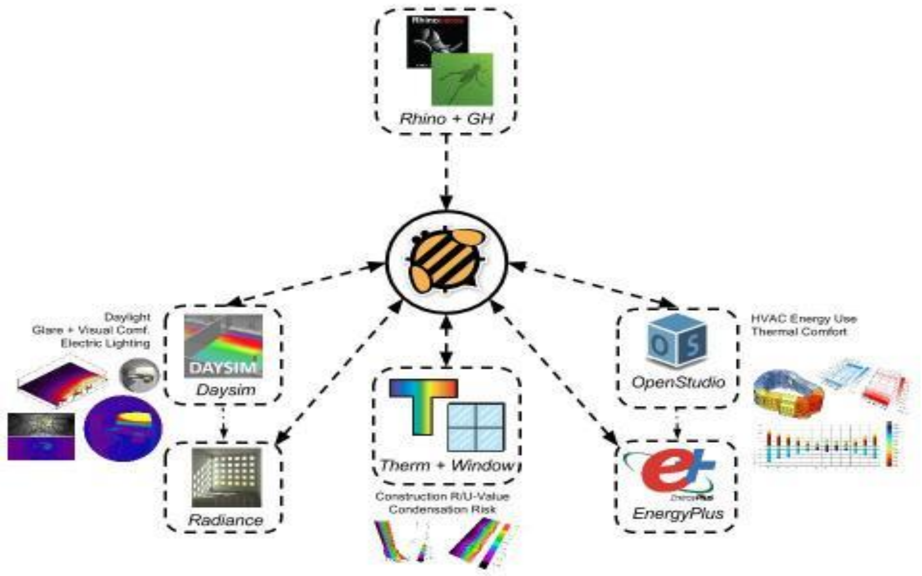


Figure 3.4. Honeybee tools for Rhinoceros

Honeybee is great tools for thermodynamic modeling that support the researcher during mid and later stages of design. Honeybee tools execute and visualizes daylight simulation using radiance energy models and envelope heat flow through construction details using Berkeley Lab THERM tools [22].

Our full methodology flowchart could by expressed in Figure 3.5. with four main design phases. Over these phases the selected tools and software were used to validate many assumptions and prove the concept that will later be used in different scenarios.

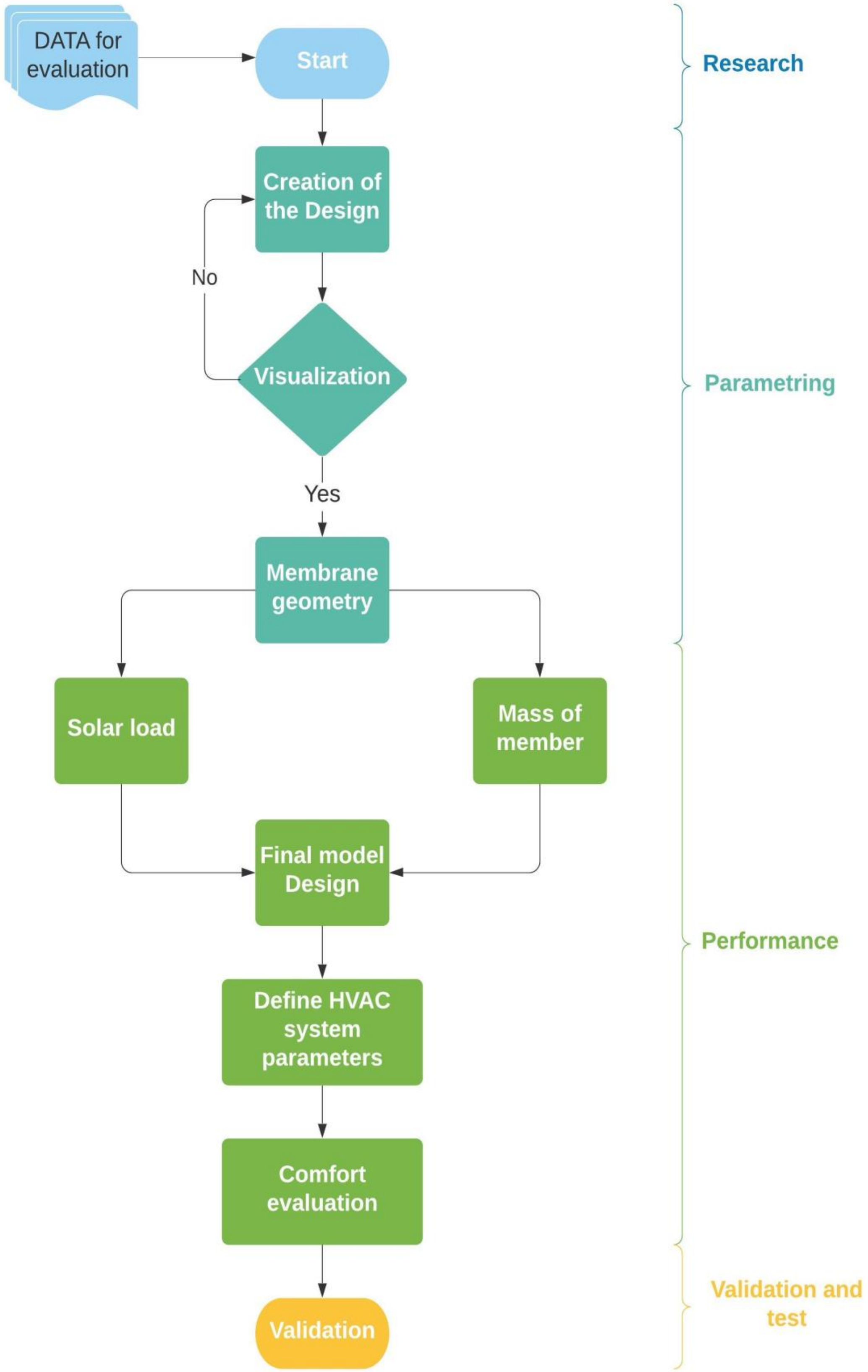


Figure 3.5. Flowchart of the methodology

3.2. Building Architecture

The building architecture of the office include two different design, complex model (Large scale based on nine areas) and simple model (Simple scale based on one area) as depicted in Figure 3.6., Figure 3.7., and Figure 3.8.

The simple scale used to validate our approach and test some basic scenarios then move to the large scale to interpret different strategies and analyze the impact of the sunlight in the different side of the building (perimeter, interior, and corners side). By default the office building has the same resistance values of the exterior and interior wall. The simulation of the 3D design take into account some parameters as follows:

- Architecture design (characteristic of the used material).
- Occupancy details.
- Setpoint of the HVAC system for summer and winter seasons.
- Electrical device and lighting details.
- Viscosity of the air.
- Fan speed.

3.3. Layout

The building design composed by different layout, in our case we focus only on one floor as presented in Figure 3.8. The floor composed by nine open space (Figure 3.6. and Figure 3.7.). The characteristic of the building are defined in Table 3.1.

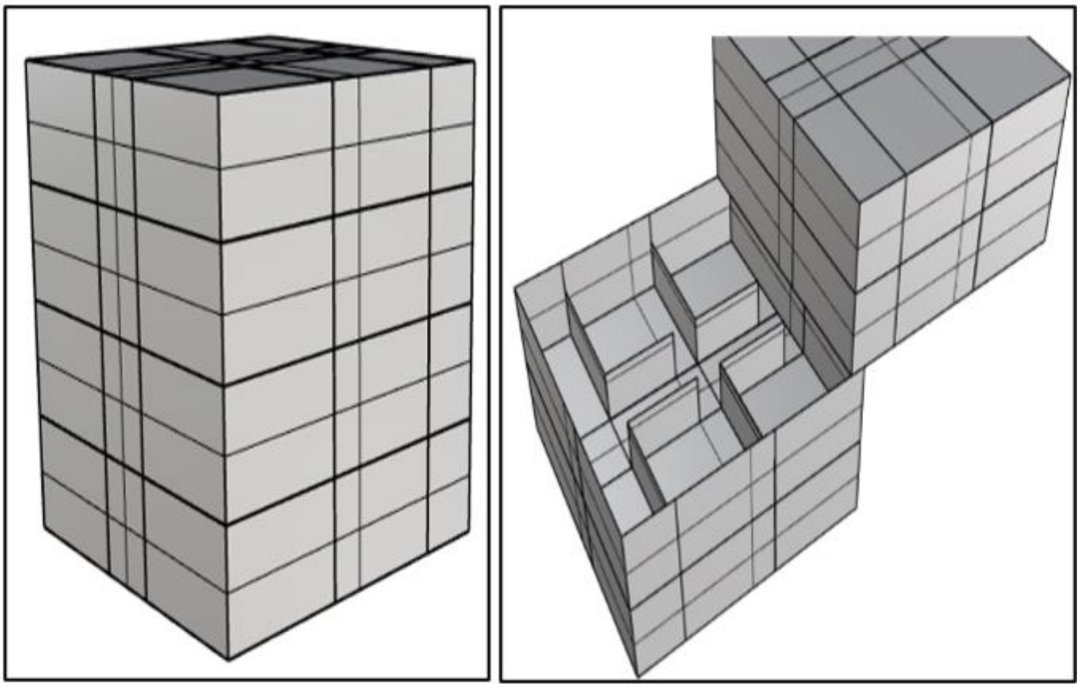


Figure 3.6. One by one building Design

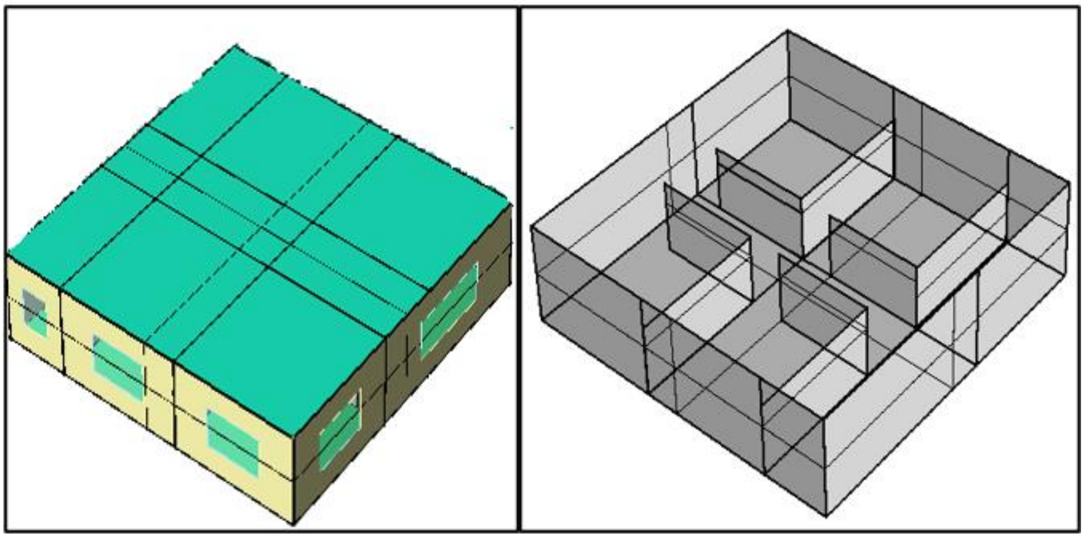


Figure 3.7. One by one building Design for one floor

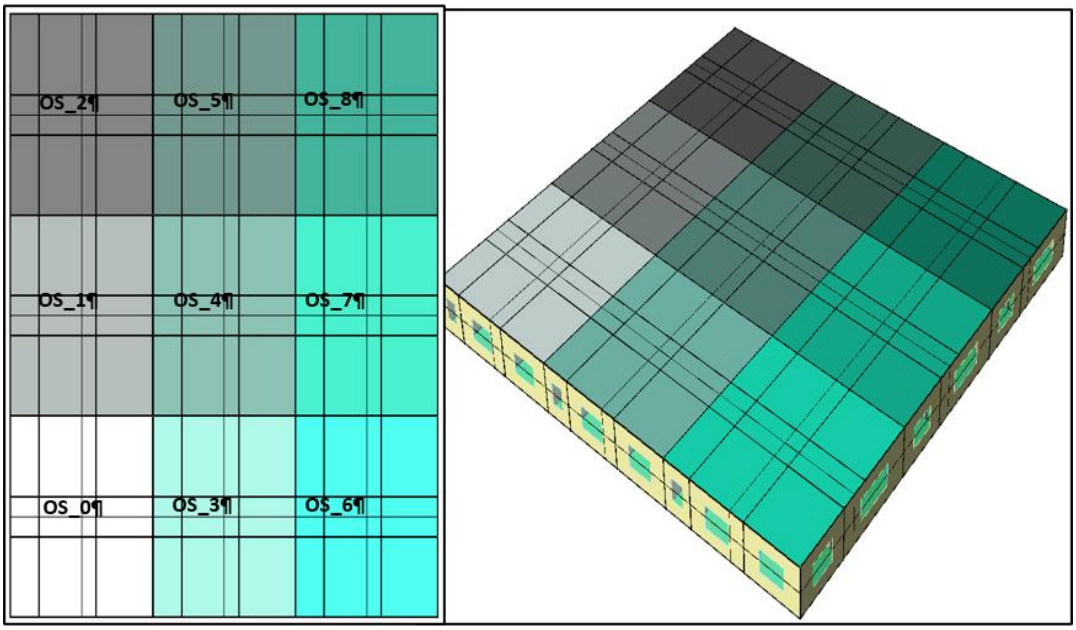


Figure 3.8. Three by three building Design

Table 3.1. Characteristic of the building model

Component	Area (m^2)
Outside wall	230.04
Outside Window	69.96
Floor	900

3.4. Thermal Resistance

The thermal resistance value of all forms are listed in Table 3.2. The high value of the thermal resistance reflect good insulation.

Table 3.2. List of the form used in the building

Form	Value (m^2K/W)
Outside wall	2.63
Inside wall	1
Outside window	0.359
Floor	1
Ceiling	4

3.5. Energy Per Zone Load

In order to calculate the energy per zone load, we have to define some parameters of the modeling interface tool [23]. These parameters focus on:

- Occupancy.
- Equipment load.
- Infiltration rate.
- Viscosity of the air.
- Density of light.

3.6. The Path Of The Sun

The path of the sun (Figure 3.9.) has a direct impact on the energy consumption of the office building. A good position of the building could help to save energy of the building (Passive solar design).

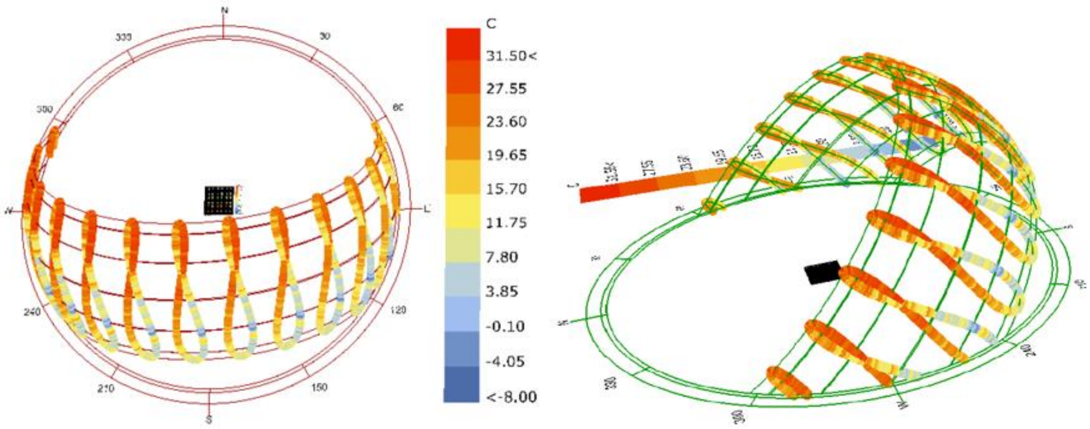


Figure 3.9. Path of the sun

CHAPTER 4. CONTROL STRATEGIES

This chapter, emphasis in variety of control strategies based on M2M communication, Enabling/Disabling HVAC system, and Fuzzy logic system to minimize energy consumption to thermal comfort constraint, with a simple and large building design. The chapter will continue present the endurance test results for some strategies.

4.1. The Proposed System Design

The outline of the proposed design depicted in Figure 4.1. is based on some elements as follow:

- 3D design of the office building (Characteristics and type of the used materials).
- Energy management system.
- Energy simulation and user comfort study [24] [25].

4.1.1. 3D building design

The 3D building design based on many parameters as follows:

- The Resistance value of all materials (m^2K/W).
- Layers of the building design .
- The solar radiation (absorbance).
- The visible light (absorbance).
- The Building model (Geometry).
- Thermal absorbance.
- Characteristic of the zone in the layer.
- The nature of the building (Office).

4.1.2. Management system

The energy management system based on the following strategies:

- Enabling or Disabling the HVAC system.
- Fuzzy logic system .
- M2M communication.
- Fuzzy logic system with M2M communication.

The management system take into account some predefined inputs as follows:

- The infiltration rate per zone.
- Equipment load per area.
- Occupancy.
- Lighting density.
- Cooling/Heating setpoint of each area.
- Electrical equipment.

4.1.3. Energy simulation

In this section the energy consumption of cooling, heating, and electrical devices are simulated by using an efficient tools like EnergyPlus [26].

4.1.4. Comfort study (ASHRAE-55)

The ASHRAE standard employ the results of Fanger's studies. Fanger's assumed that both the mean skin temperature and the sweat secretion related to internal body temperature are significant parameters influencing thermal comfort.

Fanger assumed that the heat generation of the human body is equal to its heat loss when it is exposed to a steady state thermal environment in the second part of his study. He developed a heat balance equation in terms of the internal heat generation in the human body, the conductive heat transfer from the skin through the clothing, and the radiative and convective heat loss from the exterior surface of the clothed body. In order to develop a thermal sensation index, Fanger used the 7-point psychophysical ASHRAE scale changing (–3 [Cold], -2 [Cool], -1 [Slightly cool], 0 [Neutral], +1 [Slightly warm], +2 [Warm], +3 [Hot]) [27]. Fanger assumed that a person who is slightly cool, neutral, or slightly warm is satisfied with his or her surrounding thermal environment.

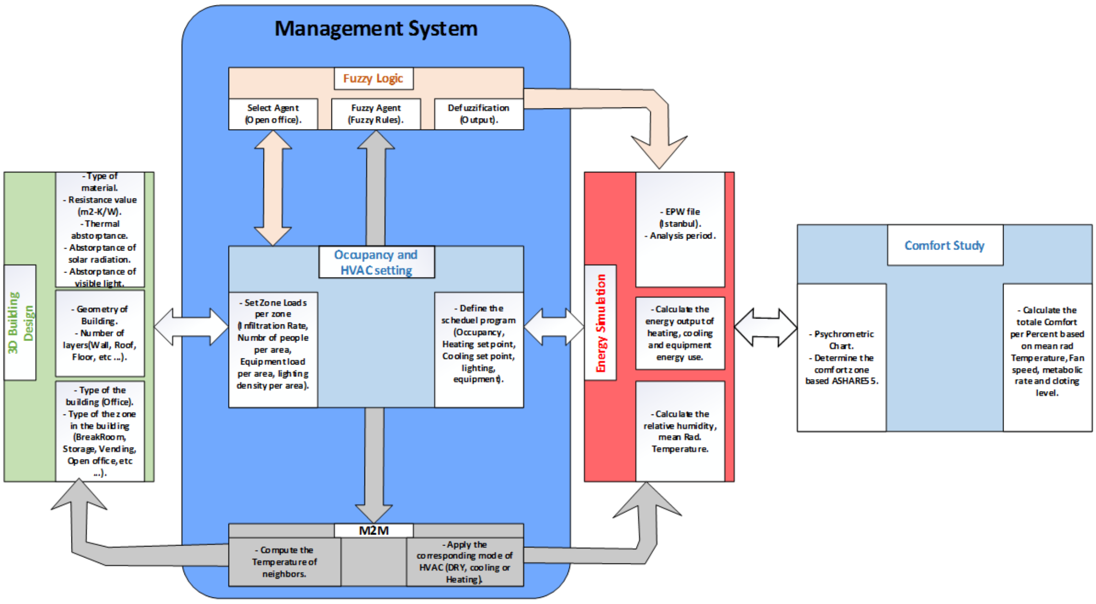


Figure 4.1. Outline of the proposed design

4.2. Control Strategies

4.2.1. Enabling/disabling HVAC based on comfortable zone (ASHRAE-55)

Based on the comfort study, the comfortable zone of the occupant represented by two polygons in the psychrometric chart, the left polygon for the winter seasons however the right one for the summer seasons. The strategy based on this comfortable zone to enable or disable the HVAC system as presented in Figure 4.2.

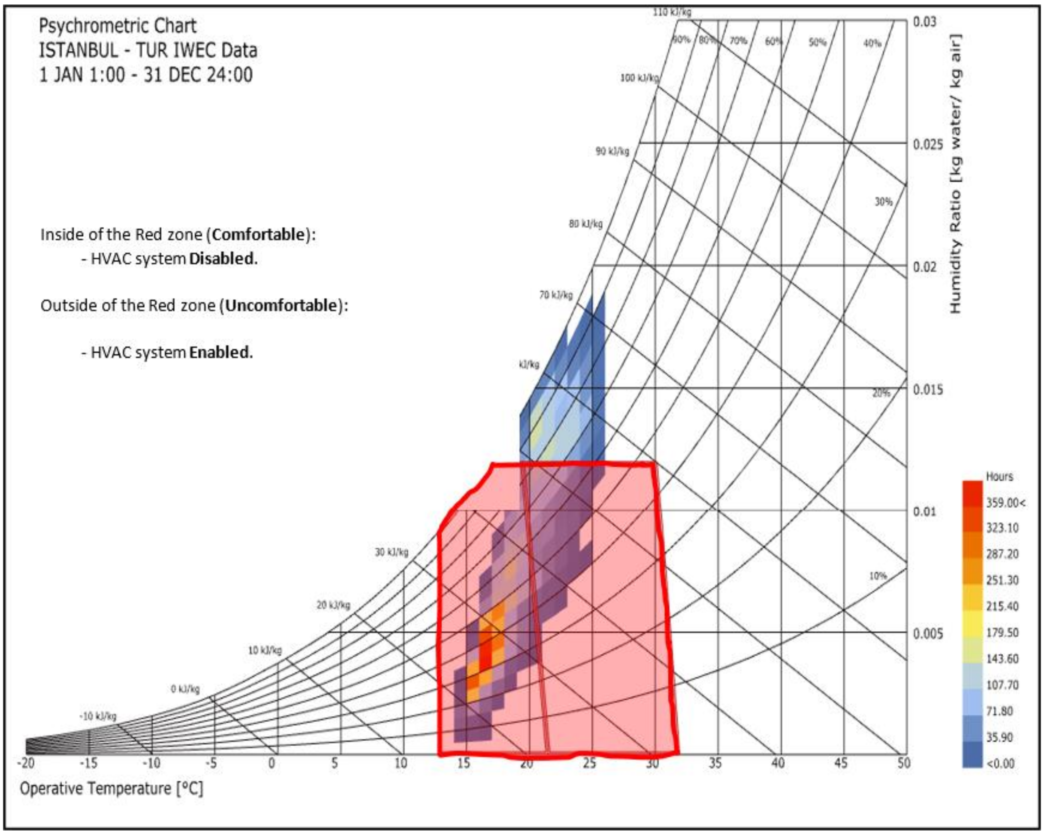


Figure 4.2. Comfortable zone in the ASHRAE Psychrometric chart [28]

4.2.2. Machine to machine

M2M communication was used as a solution in the proof of concept in our earlier publication [29]. The proposed solution was embedded in two air conditioners for two laboratories. We use the same concept for large scale of the building (nine open space OS_i) as presented in Figure 4.3. Each open space has different neighbors and could be classified with three groups as follows:

- Group 1: Connections for corner (OS_i)
- Group 2: Connections for perimeter (OS_i)
- Group 3: Connections for interior (OS_i)

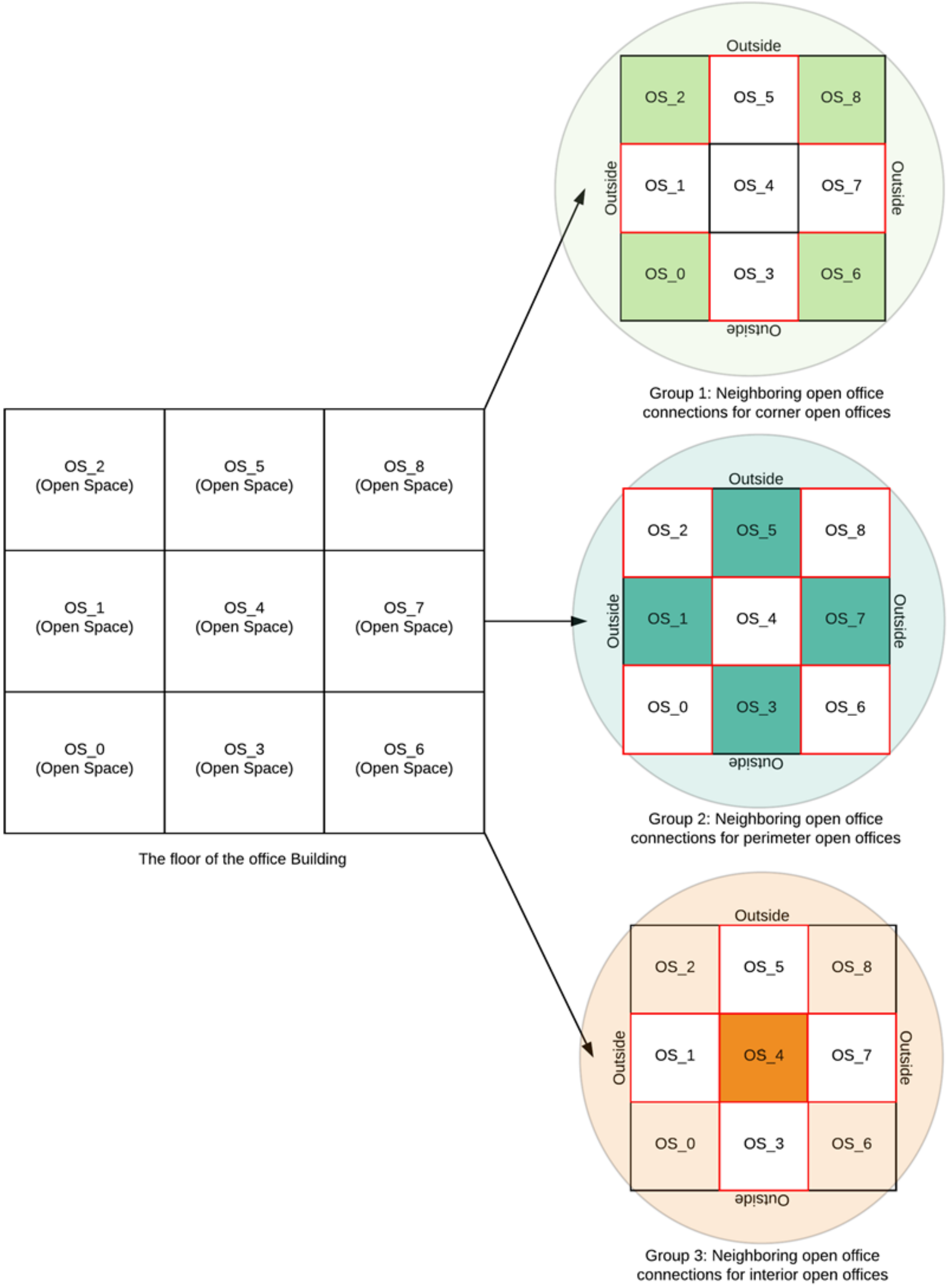
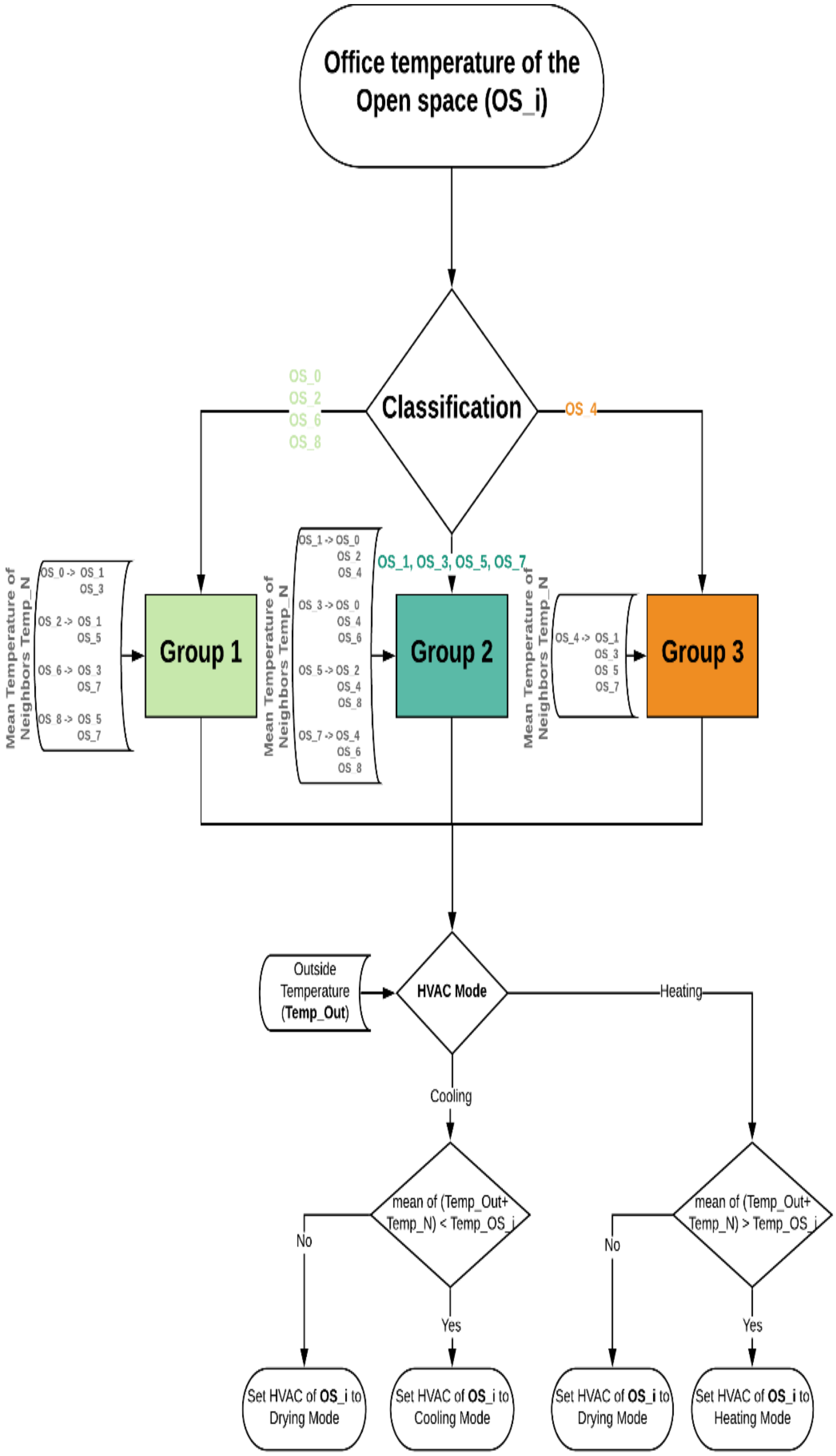


Figure 4.3. Group type of office building

Looking to this distribution, the selected HVAC mode in the air conditioner (Cooling/Heating) will be set based on the following flow chart in Figure 4.4.



(1): In case of Group 3: Temp_OS_i will be compared only with the temperature of the open work space neighbors (Temp_N).

Figure 4.4. Flow Chart of M2M approach

4.2.3. Fuzzy logic

The third strategy based on Fuzzy logic system in order to determine the new temperature of the Heating, ventilation, and air conditioning system (Figure 4.5. and Figure 4.6.) using the fuzzy if-then rules listed in Table 4.1.

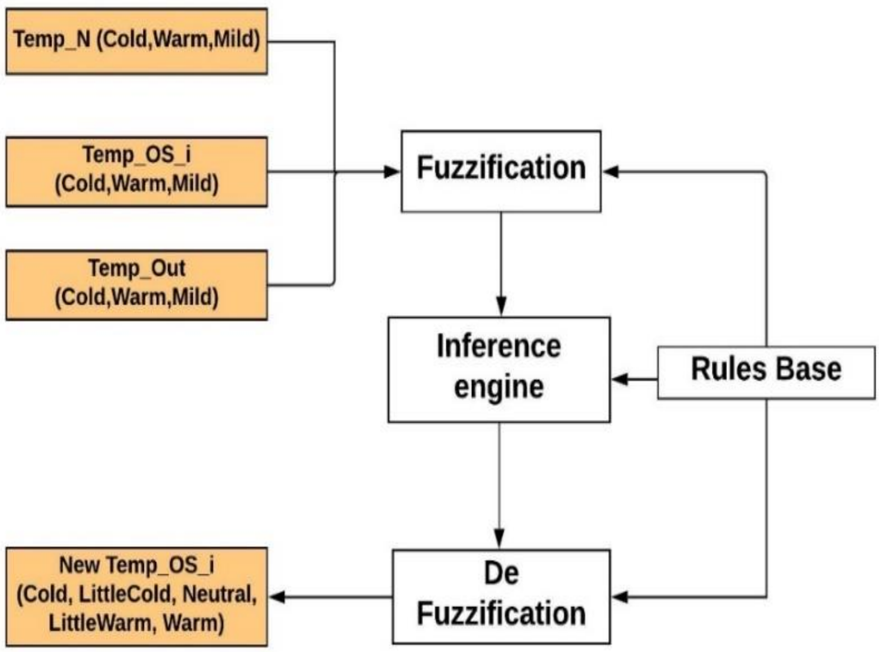


Figure 4.5. Block diagram of fuzzy logic (FL)

4.2.3.1. Membership

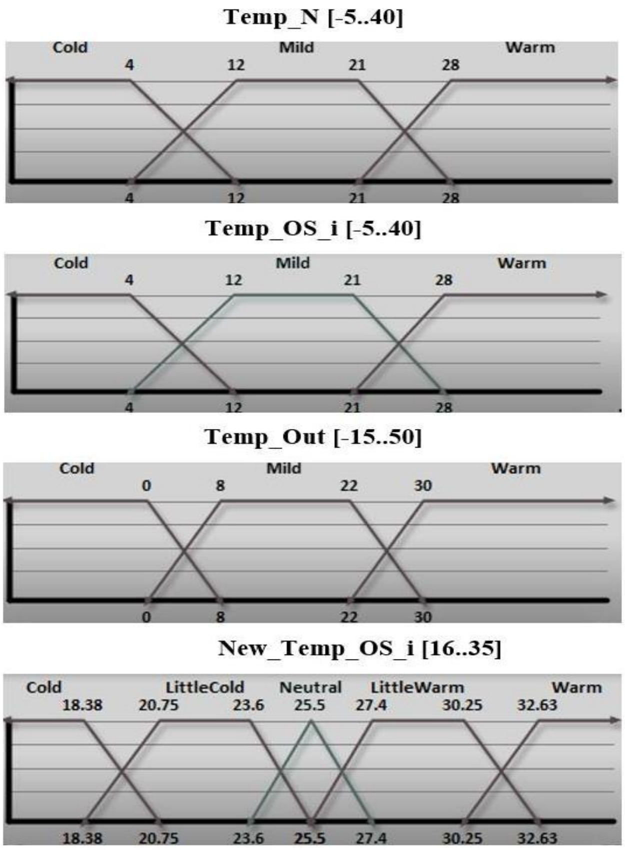


Figure 4.6. Membership functions of Input/Output

4.2.3.2. The rules of the fuzzy logic system

Table 4.1. Fuzzy logic rule base

Rule Number	Antecedents	Consequences
1	TO IS Cold AND TOSi IS Cold AND TN IS Cold	NTOSi IS Warm
2	TO IS Cold AND TOSi IS Cold AND TN IS Mild	NTOSi IS Warm
3	TO IS Cold AND TOSi IS Cold AND TN IS Warm	NTOSi IS Neutral
4	TO IS Cold AND TOSi IS Mild AND TN IS Cold	NTOSi IS LittleWarm
5	TO IS Cold AND TOSi IS Mild AND TN IS Mild	NTOSi IS Neutral
6	TO IS Cold AND TOSi IS Mild AND TN IS Warm	NTOSi IS Neutral
7	TO IS Cold AND TOSi IS Warm AND TN IS Cold	NTOSi IS LittleWarm
8	TO IS Cold AND TOSi IS Warm AND TN IS Mild	NTOSi IS Neutral

Table 4.2. Fuzzy logic rule base (Continued)

9	TO IS Cold AND TOSi IS Warm AND TN IS Warm	NTOSi IS Neutral
10	TO IS Mild AND TOSi IS Cold AND TN IS Cold	NTOSi IS LittleWarm
11	TO IS Mild AND TOSi IS Cold AND TN IS Mild	NTOSi IS Neutral
12	TO IS Mild AND TOSi IS Cold AND TN IS Warm	NTOSi IS Neutral
13	TO IS Mild AND TOSi IS Mild AND TN IS Cold	NTOSi IS LittleWarm
14	TO IS Mild AND TOSi IS Mild AND TN IS Mild	NTOSi IS Neutral
15	TO IS Mild AND TOSi IS Mild AND TN IS Warm	NTOSi IS Neutral
16	TO IS Mild AND TOSi IS Warm AND TN IS Cold	NTOSi IS LittleWarm
17	TO IS Mild AND TOSi IS Warm AND TN IS Mild	NTOSi IS Neutral
18	TO IS Mild AND TOSi IS Warm AND TN IS Warm	NTOSi IS Neutral
19	TO IS Warm AND TOSi IS Cold AND TN IS Warm	NTOSi IS Neutral
20	TO IS Warm AND TOSi IS Cold AND TN IS Mild	NTOSi IS Neutral
21	TO IS Warm AND TOSi IS Cold AND TN IS Warm	NTOSi IS LittleCold
22	TO IS Warm AND TOSi IS Mild AND TN IS Cold	NTOSi IS Neutral
23	TO IS Warm AND TOSi IS Mild AND TN IS Mild	NTOSi IS Neutral
24	TO IS Warm AND TOSi IS Mild AND TN IS Warm	NTOSi IS LittleCold
25	TO IS Warm AND TOSi IS Warm AND TN IS Cold	NTOSi IS Neutral
26	TO IS Warm AND TOSi IS Warm AND TN IS Mild	NTOSi IS LittleCold
27	TO IS Warm AND TOSi IS Warm AND TN IS Warm	NTOSi IS Cold

TO*:* Temp_Out; TOSi*:* Temp_OS_i; TN*:* Temp_N; NTOSi*:* New_Temp_OS_i

4.2.4. Fuzzy logic with M2M

By combining two different strategies (Fuzzy Logic system and M2M), we could get the advantage of M2M communication (Taking into account the ambient temperature of the neighbors) and the advantage of Fuzzy logic (Adequate setpoint of the Heating, ventilation, and air conditioning referring to the condition of the thermal environment) as depicted in Figure 4.7.

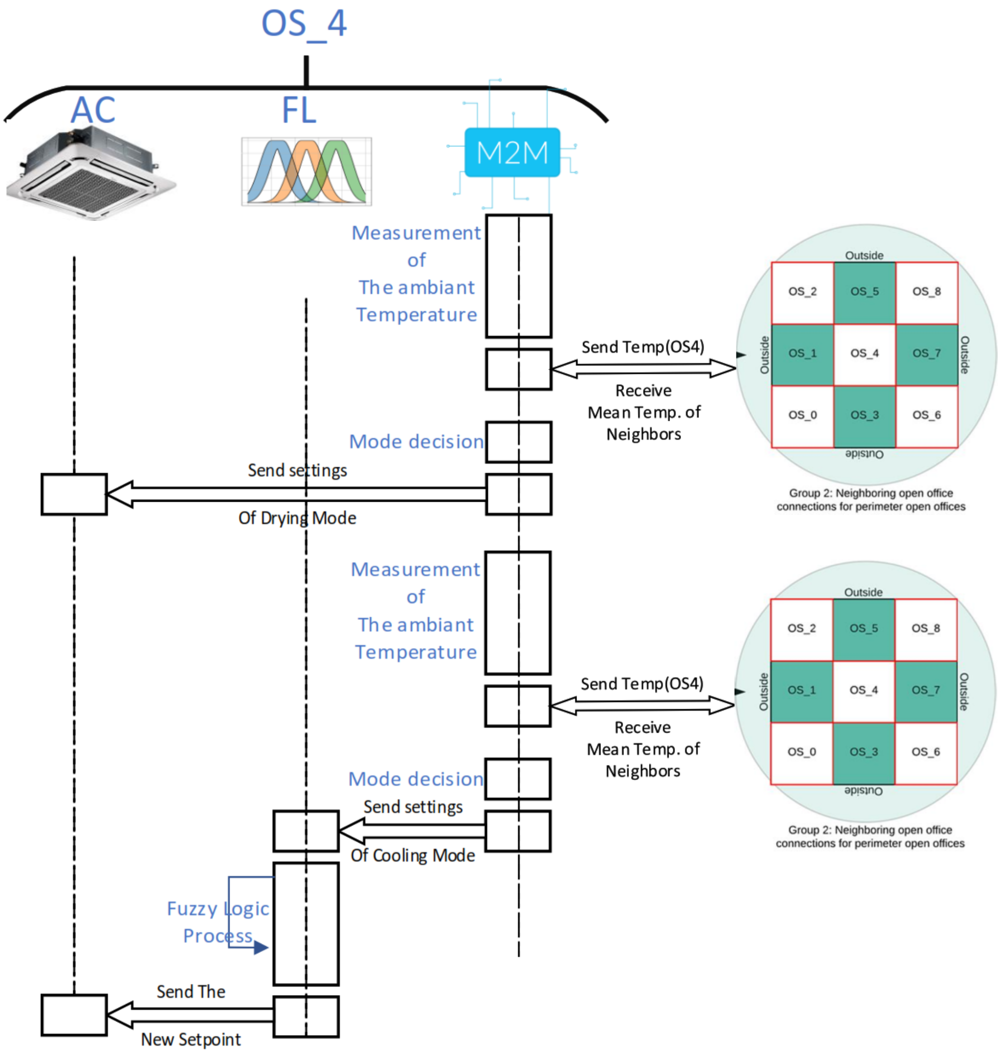


Figure 4.7. Sequence diagram of fuzzy logic with M2M communication

4.3. Simulation Results And Discussions

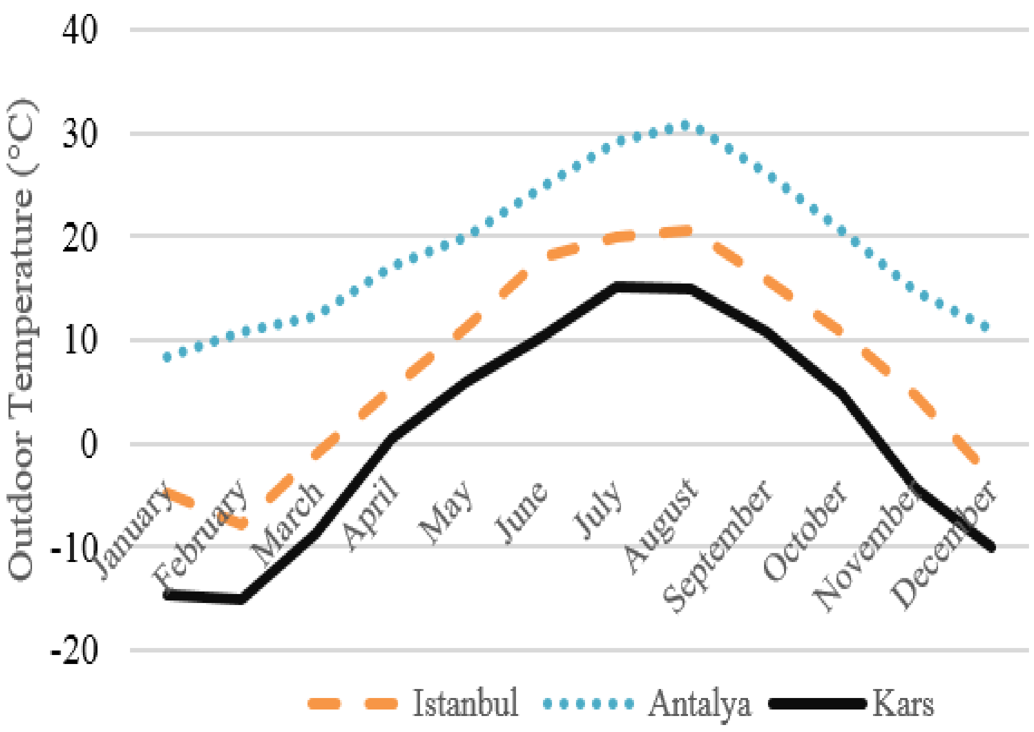
The 3D office building model designed by using efficient tools like Rhino/Grasshopper [23] has been used as a reference in order to simulate all strategies and get the simulation result. The tools gives some simple and powerful solutions to develop the building design and interpret the energy consumption and users' thermal comfort results. It offer some solution like LadyBug for daylight analysis and HoneyBee for the energy study [30].

4.3.1. Simulation results

4.3.1.1. Simple scale

The simple scale design give us the opportunity to test different weather file inputs (EPW) of Turkey (ISTANBUL [northwest], ANTALYA [Mediterranean] and KARS [Northeast]).The simulation apply different setpoint values for different seasons in the year to the Heating, ventilation, and air conditioning system.

Figure 4.8. shows the effect of the outside environment (temperature) on energy consumption. Table 4.3., Table 4.4., and Table 4.5. present the rate of the comfortable zone, the energy consumption of the Heating, ventilation, and air conditioning system, and the rate of save or loss by taking into account the outside environment (temperature) change in the year, respectively.



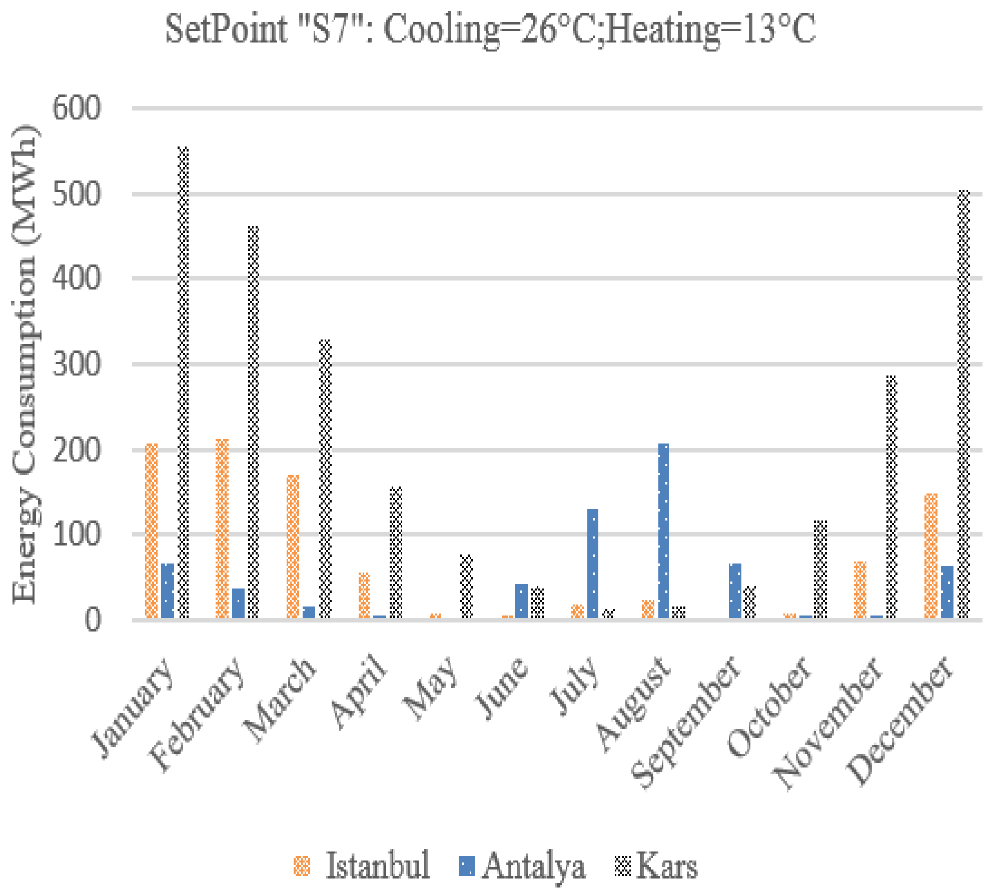


Figure 4.8. Effect of the outside temperature

Table 4.3. Energy consumption (Istanbul)

			Without saving		HVAC (ON/OFF)		Save/Gain	
State	Mode	Set Point (°C)	Energy (MWh)	Comfort (%)	Energy (MWh)	Comfort (%)	Energy (%)	Comfort (%)
S1	Cooling Heating	20 19	2560.1	78.86	1991.2	81.5	22.22	**2.64**
S2	Cooling Heating	21 18	2197.8	78.9	1757.6	81.19	20.03	2.29
S3	Cooling Heating	22 17	1872.1	78.86	1544.8	80.91	17.48	2.05
S4	Cooling Heating	23 16	1957.3	78.03	1352.5	80.46	**30.90**	2.43
S5	Cooling Heating	24 15	1333.8	77	1180.3	78.11	11.51	1.11
S6	Cooling Heating	25 14	1117.1	70.07	1022.2	70.73	8.49	0.66
S7	Cooling Heating	26 13	927.08	61.21	873.81	61.01	5.74	-0.2

Table 4.4. Energy consumption (Antalya)

			Without saving		HVAC (ON/OFF)		Save/Gain	
State	Mode	Set Point (°C)	Energy (MWh)	Comfort (%)	Energy (MWh)	Comfort (%)	Energy (%)	Comfort (%)
S1	Cooling Heating	20 19	2463.6	69.17	1656.7	70.66	**32.75**	**1.49**
S2	Cooling Heating	21 18	2072.7	69.18	1438.4	70.39	30.60	1.21
S3	Cooling Heating	22 17	1716.1	69.33	1236.3	70.26	27.96	0.93
S4	Cooling Heating	23 16	1395.8	69.63	1046.6	70.2	25.02	0.57
S5	Cooling Heating	24 15	1110.4	69.86	867.24	70.17	21.90	0.31
S6	Cooling Heating	25 14	859.8	69.57	698.39	69.71	18.77	0.14
S7	Cooling Heating	26 13	644.5	68.33	543.31	68.12	15.70	-0.21

Table 4.5. Energy consumption (Kars)

			Without saving		*HVAC (ON/OFF)*		*Save/Gain*	
State	Mode	Set Point (°C)	Energy (MWh)	Comfort (%)	Energy (MWh)	Comfort (%)	Energy (%)	Comfort (%)
S1	Cooling Heating	20 19	4029.8	98.63	3592.2	99.09	**10.86**	**0.46**
S2	Cooling Heating	21 18	3764.8	96.11	3407.1	96.27	9.50	0.16
S3	Cooling Heating	22 17	3509.5	90.62	3226	90.67	8.08	0.05
S4	Cooling Heating	23 16	3264.6	82.46	3048.1	82.45	6.63	-0.01
S5	Cooling Heating	24 15	3030.5	74.44	2873	74.42	5.20	-0.02
S6	Cooling Heating	25 14	2807.3	66.32	2699	66.18	3.86	-0.14
S7	Cooling Heating	26 13	2595.8	58.49	2527	57.99	2.65	-0.5

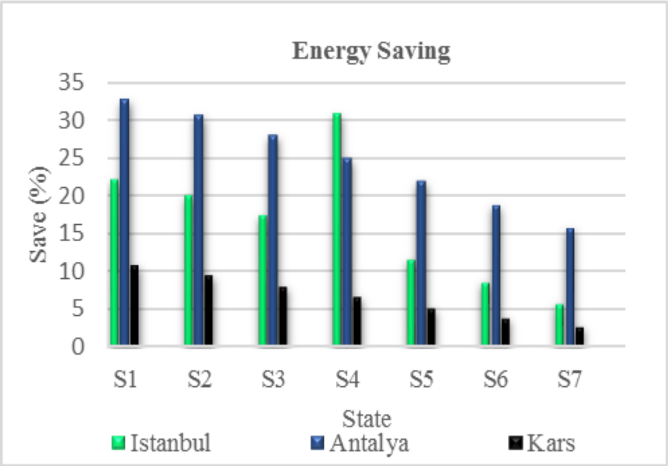


Figure 4.9. Energy Saving

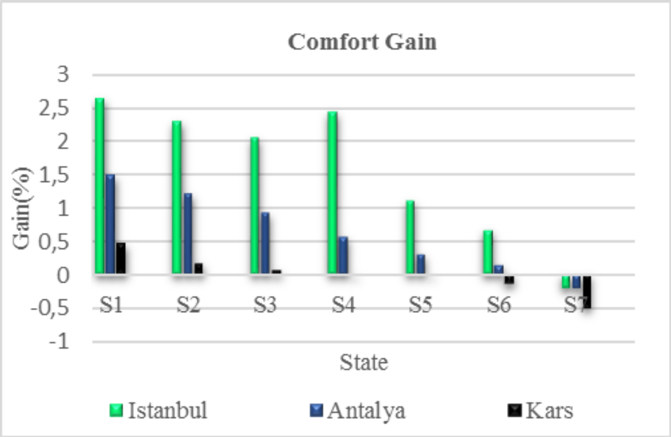


Figure 4.10. Comfort Gain

Figure 4.9. and Figure 4.10. present the impact of the outside temperature on the building for the three cities (ISTANBUL [northwest], ANTALYA [Mediterranean] and KARS [Northeast]). In comparison with other cities the results shows that Istanbul present the best comfort gain.

Comfort zone of the three cities (ISTANBUL [northwest], ANTALYA [Mediterranean] and KARS [Northeast]) depicted in Figure 4.11., Figure 4.12., and Figure 4.13.

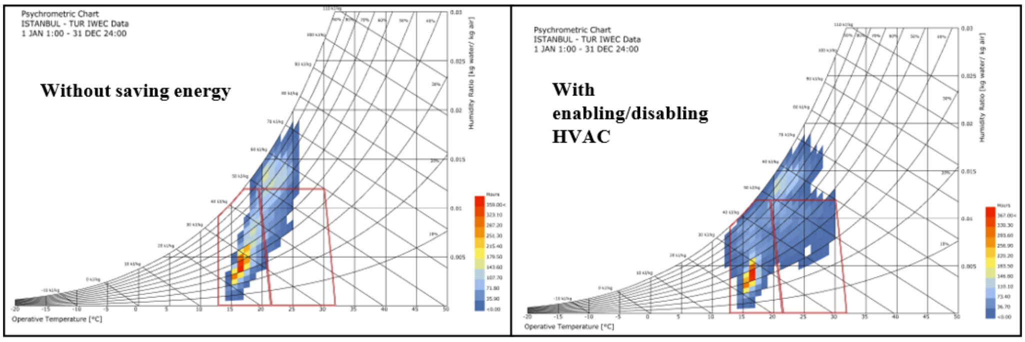


Figure 4.11. Comfort zone (Istanbul [S1])

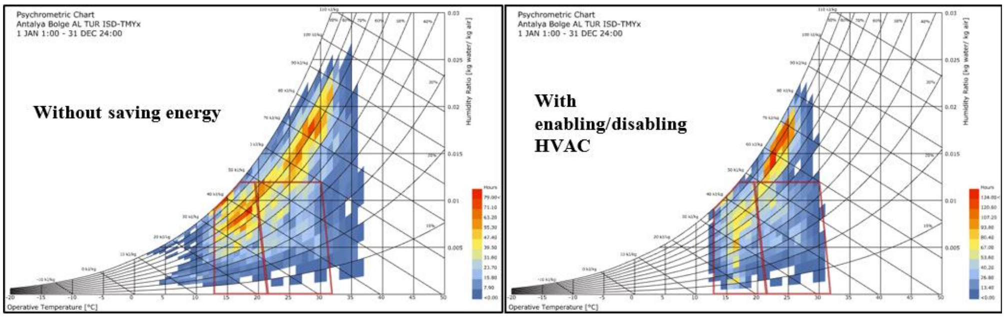


Figure 4.12. Comfort zone (Antalya [S1])

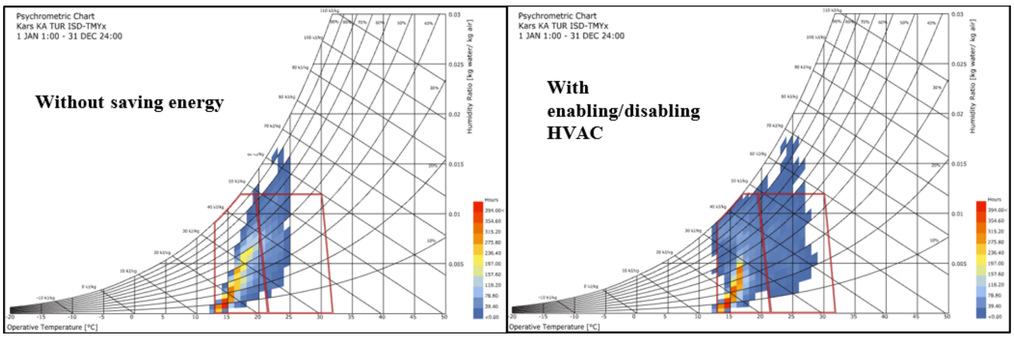


Figure 4.13. Comfort zone (Kars [S1])

The promising results given by enabling/disabling HVAC strategy, precisely in terms of energy save motivate us to continue the implementation of different strategies.

4.3.1.2. Large scale

Enabling and Disabling HVAC system strategy for all open workspaces(The ambient temperature of the proposed building model [nine open workspace] is dependent with the predefined setpoint (HVAC system) of each open work space and the neighbors impact).

Table 4.6. shows the performance of the strategy in term of energy saving and comfort gain for three cities (ISTANBUL [northwest], ANTALYA [Mediterranean] and KARS [Northeast]).

Table 4.6. Save on energy and gain on comfort of the city of Istanbul (With/Without enabling and disabling HVAC)

State		*S1*		*S2*		*S3*		*S4*	
		Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
Office Number	0	**22.22**	2.4	20.03	1.95	17.48	2.26	14.59	1.28
	1	**22.22**	1.98	20.03	1.78	17.48	2.02	14.60	0.98
	2	**22.22**	2.12	20.04	1.79	17.48	2.1	14.60	1.03
	3	**22.22**	2	20.03	1.74	17.46	1.91	14.59	1.11
	4	**22.22**	1.69	20.03	1.4	17.48	1.83	14.60	0.83
	5	**22.23**	1.79	20.03	1.56	17.49	1.81	14.59	0.86
	6	**22.22**	2.34	20.03	1.91	17.48	2.27	14.59	1.22
	7	**22.22**	2	20.03	1.74	17.49	1.96	14.60	1
	8	**22.22**	2.08	20.04	1.72	17.48	2.09	14.60	0.98

State		S5		S6		S7	
		Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
Office Number	0	11.51	**3.04**	8.50	0.61	5.74	-0.33
	1	11.51	**2.21**	8.50	0.43	5.74	-0.62
	2	11.50	**2.85**	8.50	0.39	5.75	-0.64
	3	11.51	**2.24**	8.49	0.49	5.74	-0.6
	4	11.51	**1.82**	8.49	0.26	5.74	-0.97
	5	11.51	**2.08**	8.50	0.29	5.75	-0.9
	6	11.51	**3**	8.51	0.62	5.74	-0.3
	7	11.51	**2.21**	8.49	0.4	5.75	-0.66
	8	11.50	**2.76**	8.50	0.32	5.75	-0.69

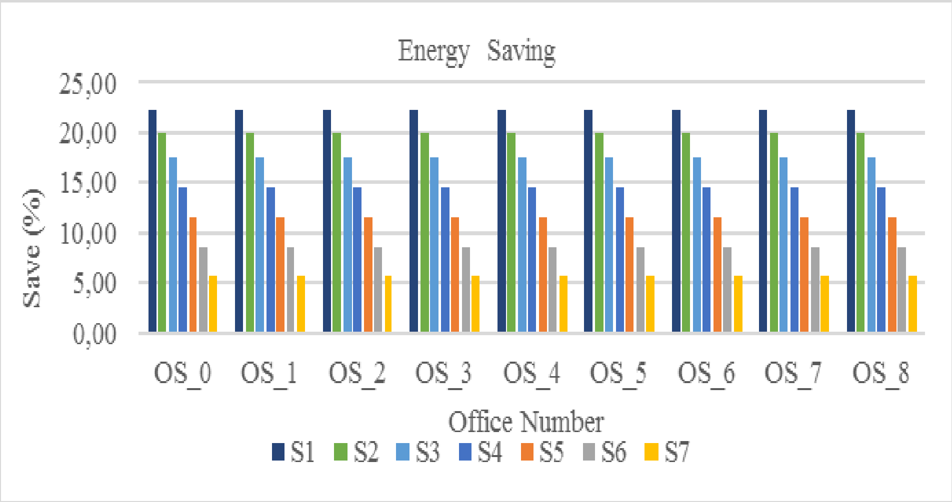


Figure 4.14. Save energy (Istanbul)

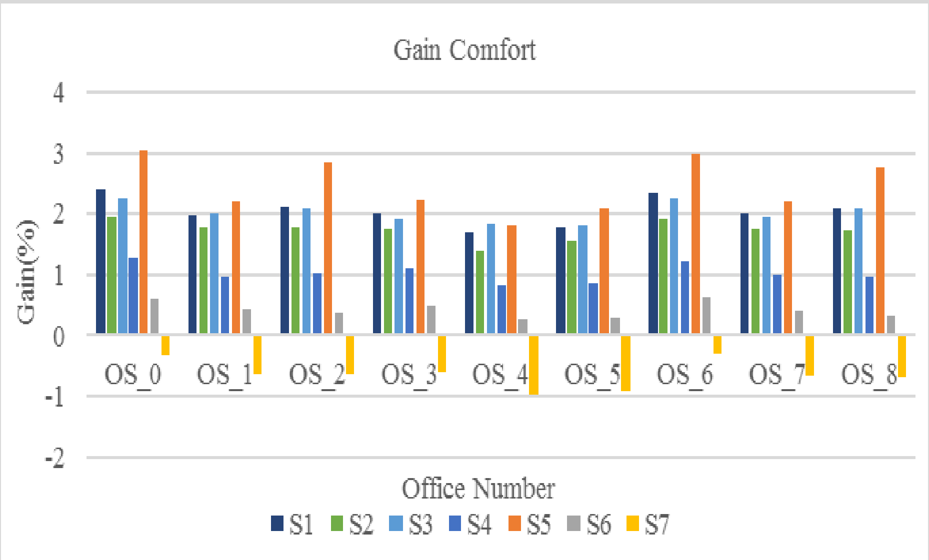


Figure 4.15. Gain comfort (Istanbul)

Figure 4.14. and Figure 4.15. present the rate of comfort gain and energy saving. S1 present the optimum result of energy saving and S5 present the optimum result of comfort gain, compared to all open workspaces of the building.

M2M strategy for OS_4(The effect of the neighbors on the open space number four in terms of comfort gain and energy saving as illustrated in Table 4.7.).

Table 4.7. Total Energy saving and comfort gain for one year of the city of Istanbul (With/Without M2M)

State	*S1*		*S2*		*S3*		*S4*	
Office Number	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
0	0.00	-0.01	0.00	0.09	0.00	0.07	0.00	0.11
1	-0.01	-0.26	-0.02	1.45	-0.02	1.72	-0.02	1.31
2	0.00	-0.02	0.00	0.14	0.00	0.20	0.00	0.10
3	-0.01	-0.27	-0.02	1.52	-0.02	1.59	-0.02	1.31
4	**40.07**	**1.23**	**35.74**	**-1.00**	**28.78**	**-1.66**	**20.79**	**-4.91**
5	-0.01	-0.31	-0.02	1.55	-0.02	1.71	-0.02	1.32
6	0.00	-0.03	0.00	0.08	0.00	0.15	-0.01	0.11
7	-0.01	-0.24	-0.02	1.51	-0.02	1.67	-0.02	1.34
8	0.00	0.00	0.00	0.10	0.00	0.20	0.00	0.12

State	S5		S6		S7	
Office Number	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
0	0.00	0.01	0.00	-0.02	0.00	0.01
1	-0.01	0.03	0.00	-0.53	0.00	0.07
2	0.00	0.00	0.00	-0.03	0.00	0.00
3	0.00	0.04	0.00	-0.49	0.00	0.04
4	**7.91**	**-4.71**	**-3.59**	**-5.50**	**-16.05**	**1.69**
5	-0.01	0.02	0.00	-0.47	0.00	-0.03
6	0.00	0.01	0.00	-0.02	0.00	0.00
7	-0.01	0.05	0.00	-0.53	0.00	0.09
8	0.00	-0.01	0.00	-0.04	0.00	-0.01

Fuzzy logic system strategy for OS_4 (The effect of the neighbors on the Open space number four in terms of comfort gain and energy saving as illustrated in Table 4.8.).

Table 4.8. Total Energy saving and comfort gain for one year of the city of Istanbul

State	*S1*		*S2*		*S3*		*S4*	
Office Number	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
0	0.00	0.01	0.00	-0.01	0.01	0.01	0.01	0.03
1	0.03	0.06	0.04	0.21	0.05	0.31	0.07	0.32
2	0.00	0.04	0.00	0.02	0.01	0.09	0.01	0.01
3	0.03	0.05	0.04	0.18	0.05	0.22	0.07	0.37
4	**-67.44**	**0.00**	**-100.73**	**-0.52**	**-141.07**	**-1.09**	**-189.68**	**-1.55**
5	0.03	0.09	0.04	0.20	0.06	0.42	0.06	0.30
6	0.00	0.03	0.00	-0.01	0.01	0.04	0.01	0.02
7	0.03	0.09	0.04	0.20	0.05	0.30	0.07	0.29
8	0.00	0.01	0.00	0.01	0.01	0.06	0.01	0.00

State	S5		S6		S7	
Office Number	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
0	0.01	0.18	0.01	0.65	0.01	0.65
1	0.08	1.14	0.11	5.16	0.13	8.85
2	0.00	0.24	0.01	0.60	0.01	0.70
3	0.09	1.09	0.10	4.78	0.13	8.69
4	**-247.60**	**-1.42**	**-318.08**	**2.54**	**-406.01**	**12.89**
5	0.08	1.15	0.10	5.46	0.13	8.75
6	0.01	0.20	0.01	0.63	0.01	0.75
7	0.08	1.15	0.11	5.14	0.13	8.79
8	0.00	0.20	0.01	0.60	0.01	0.68

Fuzzy logic with M2M study for OS_4 (The effect of the neighbors on the Open space number four in terms of comfort gain and energy saving as illustrated in Table 4.9.).

Table 4.9. Total Energy saving and comfort gain for one year of the city of Istanbul

State		*S1*		*S2*		*S3*		*S4*	
		Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
Office Number	0	0.00	-0.01	0.00	-0.02	0.01	-0.03	0.00	0.01
	1	0.01	-0.30	0.02	-0.24	0.04	-0.27	0.05	-0.13
	2	0.00	-0.02	0.00	-0.01	0.01	-0.02	0.01	0.01
	3	0.01	-0.30	0.02	-0.33	0.04	-0.36	0.05	-0.11
	4	**-22.78**	**2.20**	**-45.71**	**1.74**	**-78.43**	**1.69**	**-118.79**	**1.70**
	5	0.02	-0.36	0.02	-0.36	0.04	-0.35	0.04	-0.21
	6	0.00	-0.03	0.00	-0.01	0.01	0.00	0.00	-0.02
	7	0.02	-0.28	0.02	-0.28	0.04	-0.27	0.05	-0.14
	8	0.00	0.00	0.00	-0.03	0.01	-0.01	0.01	-0.01

State		S5		S6		S7	
		Energy (%)	Comfort (%)	Energy (%)	Comfort (%)	Energy (%)	Comfort (%)
Office Number	0	0.01	0.17	0.01	0.58	0.01	0.65
	1	0.07	0.89	0.10	4.94	0.12	8.56
	2	0.00	0.17	0.01	0.58	0.01	0.64
	3	0.08	0.84	0.09	4.58	0.12	8.50
	4	**-187.67**	**1.10**	**-256.38**	**3.93**	**-340.17**	**14.16**
	5	0.07	0.94	0.10	5.18	0.12	8.55
	6	0.01	0.16	0.01	0.59	0.01	0.69
	7	0.07	0.89	0.10	4.96	0.12	8.58
	8	0.00	0.14	0.01	0.56	0.01	0.65

4.3.2. Discussions

When buildings have a complex and large design the challenge of satisfying the occupant's in terms of comfort level and saving energy become more difficult. The results for the occupant's thermal comfort and the energy consumptions of all strategies are presented in Table 4.10. and Table 4.11.

4.3.2.1. Comparison of all studies or methodologies

Table 4.10. Summary results of all strategies

	Energy (MWh)				*Comfort (%)*			
State	Without strategies	FL	FL&M2M	M2M	Without strategies	FL	FL&M2M	M2M
S1	2558.70	4283.90	3141.30	1533.3	80.57	80.57	82.77	81.80
S2	2196.4	4408.9	3200.4	1411.5	80.52	80.00	82.26	79.52
S3	1870.9	4510.2	3338.2	1332.5	80.52	79.43	82.21	78.86
S4	1582.6	4584.4	3462.6	1253.5	80.69	79.14	82.39	75.78
S5	1333.20	4633.50	3834.60	1227.5	80.44	79.02	80.54	75.73
S6	1116.4	4667.5	3978.6	1156.5	76.39	78.93	80.32	70.89
S7	926.61	4688.30	4078.30	1075.2	66.00	78.89	80.16	67.69

Table 4.11. Gain compared to Without Enabling/Disabling HVAC

	Energy Saving (%)						
State / *Strategies*	S1	S2	S3	S4	S5	S6	S7
Enabling/Disabling HVAC	22.22	20.03	17.48	14.59	**11.51**	**8.50**	**5.74**
FL	-67.44	-100.73	-141.07	-189.68	-247.60	-318.08	-406.01
FL&M2M	-22.78	-45.71	-78.43	-118.79	-187.67	-256.38	-340.17
M2M	**40.07**	**35.74**	**28.78**	**20.79**	7.91	-3.59	-16.05
	Gain Comfort (%)						
State / *Strategies*	S1	S2	S3	S4	S5	S6	S7
Enabling/Disabling HVAC	**2.4**	**1.95**	**2.26**	1.28	**3.04**	0.61	-0.33
FL	0.00	-0.52	-1.09	-1.55	-1.42	2.54	12.89
FL&M2M	2.20	1.74	1.69	**1.70**	0.10	**3.93**	**17.00**
M2M	1.23	-1.00	-1.66	-4.91	-4.71	-5.50	1.69

The outdoor temperature has a direct impact on the energy consumption for all strategies as presented in Figure 4.16. On the other side, Figure 4.17. shows that fuzzy logic and M2M with fuzzy logic strategy present the worst solution in terms of gain, and the energy consumption even with important comfort gain. As a results, Enabling/Disabling HVAC system and M2M strategies must be the adequate solution by reducing energy consumption with an acceptable gain of users comfort.

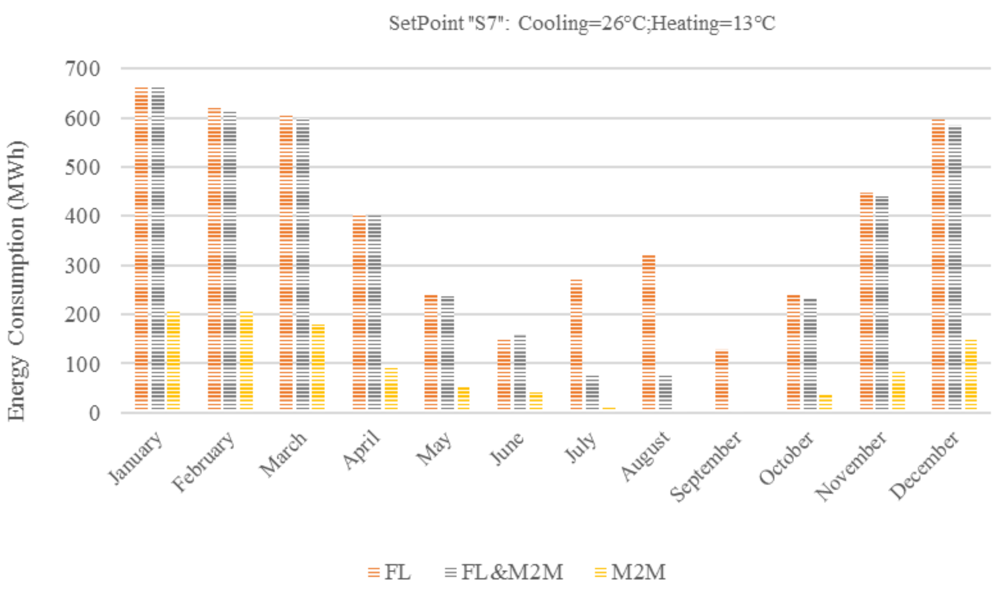


Figure 4.16. Effect of the outside temperature on energy consumption

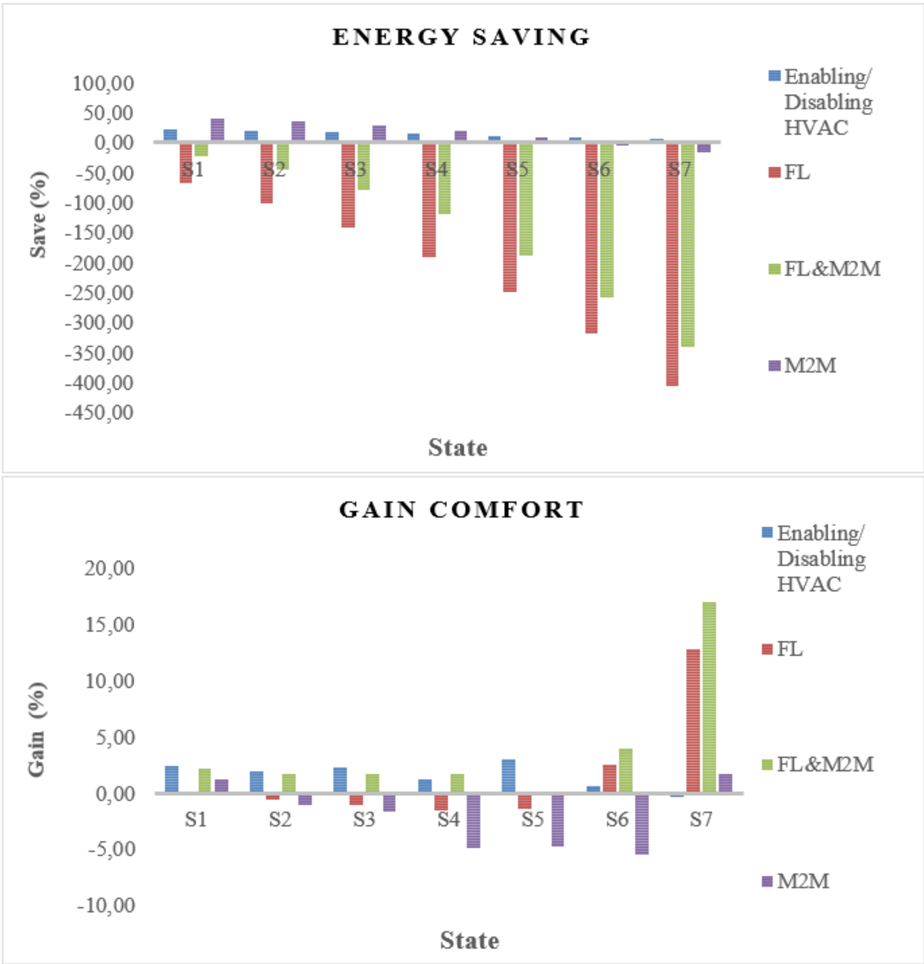


Figure 4.17. Summary results of all strategies

4.4. Sensitivity Analysis

In this section we will focus only on the endurance test for two strategies Enabling/Disabling HVAC system and M2M strategies in terms of non-uniform occupancy and heat effect.

4.4.1. Non-uniform heat load effects

In the case of realistic scenario the heat loads will not be uniform. Ten random sets of heat loads (between 500 Watts and 1500 Watts) were applied to nine open space of the proposed building design as illustrated in Table 4.12., Figure 4.19., and Figure 4.20.

Table 4.12. The values of the randomly generated ten sets of heat load for 3x3-open office building

Set		1	“2	3	4	5	6	7	8	9	10
Heat load (W) Open space number	0	813.3	757.6	1159.7	1128.2	786.4	1170.9	1142.8	1143.3	1338.7	737.1
	1	1285.5	700.7	1383.7	1128.6	933.3	1285.8	792.3	600.5	866.4	987.2
	2	1164.1	1467.4	1044.8	1305.4	1060.2	1085.7	835.7	1350.9	640.0	1458.4
	3	959.8	526.6	1159.9	964.9	1389.4	939.0	1151.6	780.0	589.1	765.9
	4	738.6	1092.8	503.0	716.5	1132.0	1139.3	1248.9	625.0	522.8	708.0
	5	1413.4	581.2	896.5	1152.9	834.1	755.3	1295.7	1300.1	1146.8	815.4
	6	1013.6	829.0	1465.1	1426.5	1128.0	1372.4	1245.3	883.4	1296.6	1163.7
	7	1418.1	1437.0	666.0	1085.3	1227.7	977.7	1372.7	1022.7	528.8	1356.5
	8	1171.1	583.9	1141.4	882.8	971.7	732.7	613.0	632.3	1107.1	1173.8
Average Heat load		**1108.6**	**886.24**	**1046.6**	**1087.9**	**1051.4**	**1050.9**	**1077.5**	**926.49**	**892.90**	**1018.4**

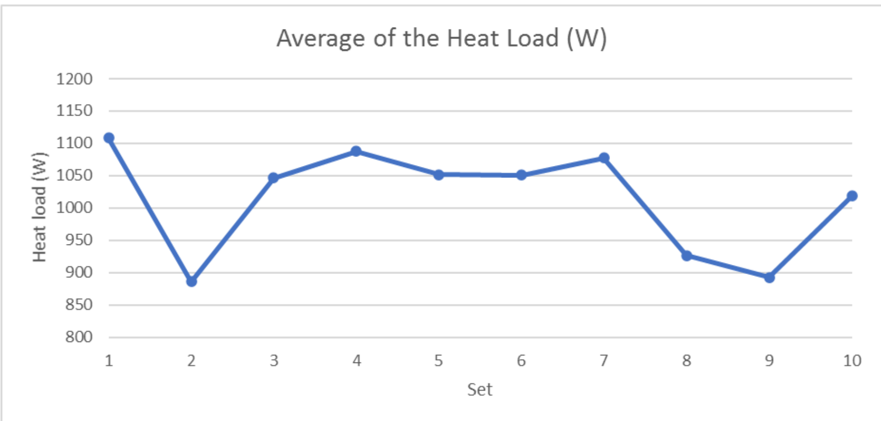


Figure 4.18. Average Heat load

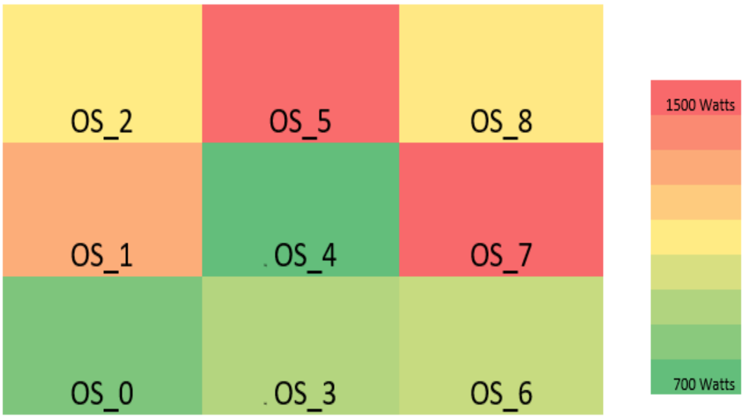


Figure 4.19. Heat load example

The low ambient temperature and the lower heat load in the open office (OS_i) impact the energy consumption and user comfort. Figure 4.20. shows the mean results of comfort gain and energy consumption.

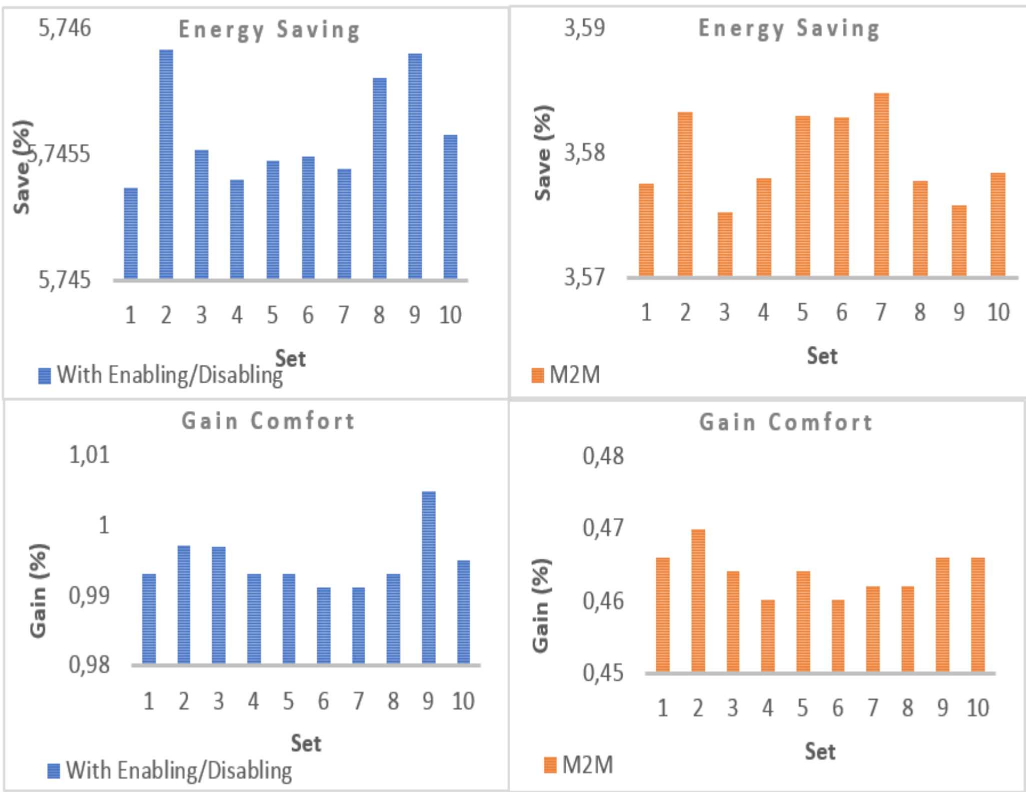


Figure 4.20. Result of energy saving and comfort gain (Non-uniform Heat load)

4.4.2. Non-uniform occupancy effects

In the case of realistic scenario the number of people in the open space will not be uniform. The occupancies differs from one open office to another. Ten random sets of the occupancy (between 0.2 pp/m^2 to 0.5 pp/m^2 people) were applied to nine open space of the proposed building design as illustrated in Table 4.13., Figure 4.21., and Figure 4.22.

Table 4.13. The values of the randomly generated ten sets of occupancy for a 3x3-open office building

Set		1	2	3	4	5	6	7	8	9	10
Occupancy (pp/m^2) Open space number	0	0.06	0.08	0.37	0.36	0.21	0.45	0.27	0.27	0.02	0.07
	1	0.28	0.07	0.22	0.13	0.10	0.41	0.28	0.08	0.16	0.15
	2	0.48	0.15	0.49	0.29	0.25	0.44	0.32	0.47	0.42	0.31
	3	0.49	0.30	0.46	0.25	0.19	0.07	0.39	0.48	0.32	0.37
	4	0.41	0.18	0.16	0.29	0.15	0.16	0.45	0.38	0.22	0.13
	5	0.21	0.24	0.24	0.23	0.03	0.25	0.06	0.45	0.06	0.31
	6	0.25	0.33	0.21	0.39	0.13	0.17	0.13	0.07	0.21	0.26
	7	0.49	0.15	0.03	0.49	0.15	0.46	0.43	0.43	0.35	0.45
	8	0.03	0.35	0.32	0.15	0.07	0.04	0.41	0.38	0.13	0.23
Average of Occupancy (pp/m^2)		**0.30**	**0.20**	**0.28**	**0.29**	**0.14**	**0.27**	**0.30**	**0.33**	**0.21**	**0.25**

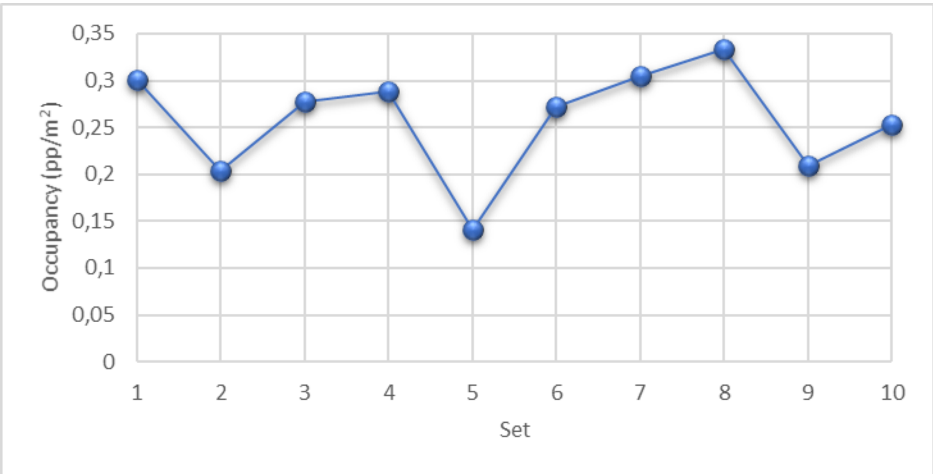


Figure 4.21. Average of occupancy

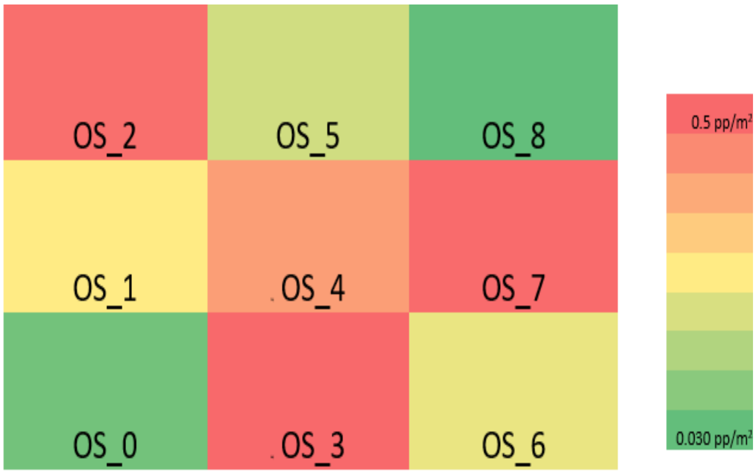


Figure 4.22. Heat load example

Figure 4.23. presents the mean results of comfort gain and energy saving for each open space (OS_i) when the number of people per area changes.

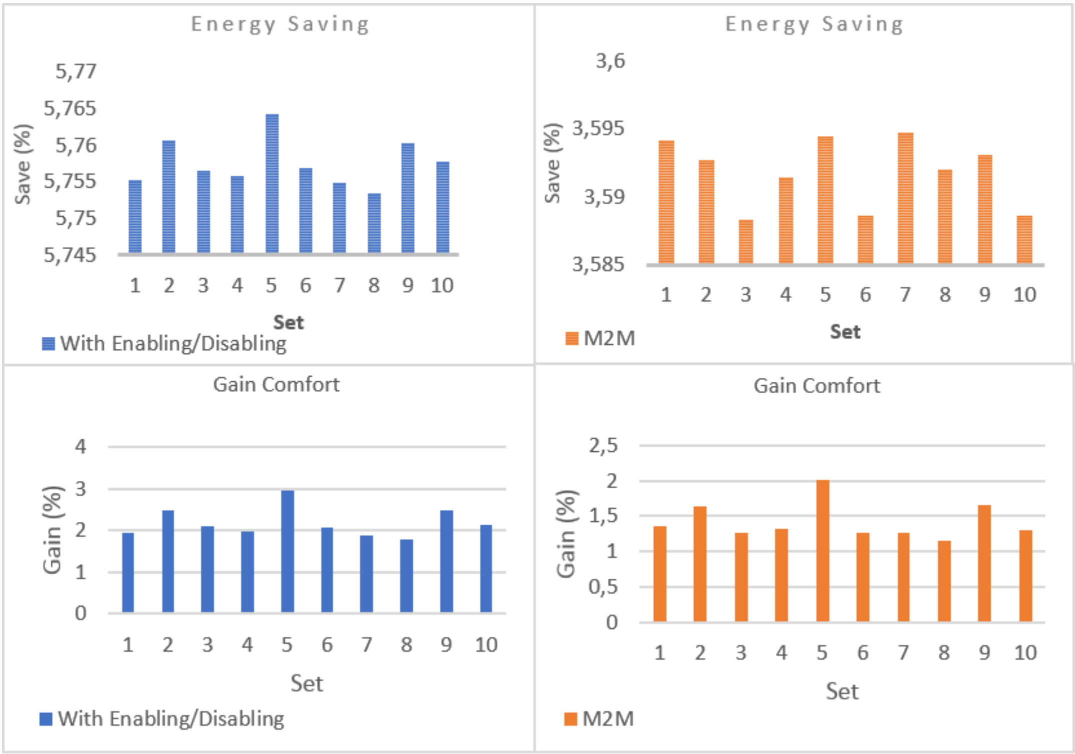


Figure 4.23. Result of energy saving and comfort gain (Non-uniform occupancy)

CHAPTER 5. LIGHT CONTROL SYSTEM

This chapter, interpret the light effect in different seasons and times of day on the energy consumption of the building and a new smart control system has been proposed and simulated.

5.1. Lighting In The Rooms

While analyzing the light in the room, it is important to get into account some parameters like location of the building, shading, glazing type, season, month and time of the day.

A good interpretation of the illuminance threshold in lux beyond which electric lights will be dimmed if there is sufficient daylight in the room can lead to save a big amount of energy per year especially for office building. By including these parameters to the BEMS we could get up to 30% and more for the total consumption of electricity, and up to 80% reduction of electricity consumption for lighting [31].

5.2. Smart Control System With Daylights

The light system in offices is not smart-controlled for the most part due to the extra cost and reliability. Most of such smart light systems consume more light than what they actually need. Accordingly, the energy consumed by light system can represent an important source of consumption in buildings. Figure 5.1. show the proposed design of two smart LEDs for nine open offices (OS) in the office building as an example of how to implement some sensors on the existing LEDs.

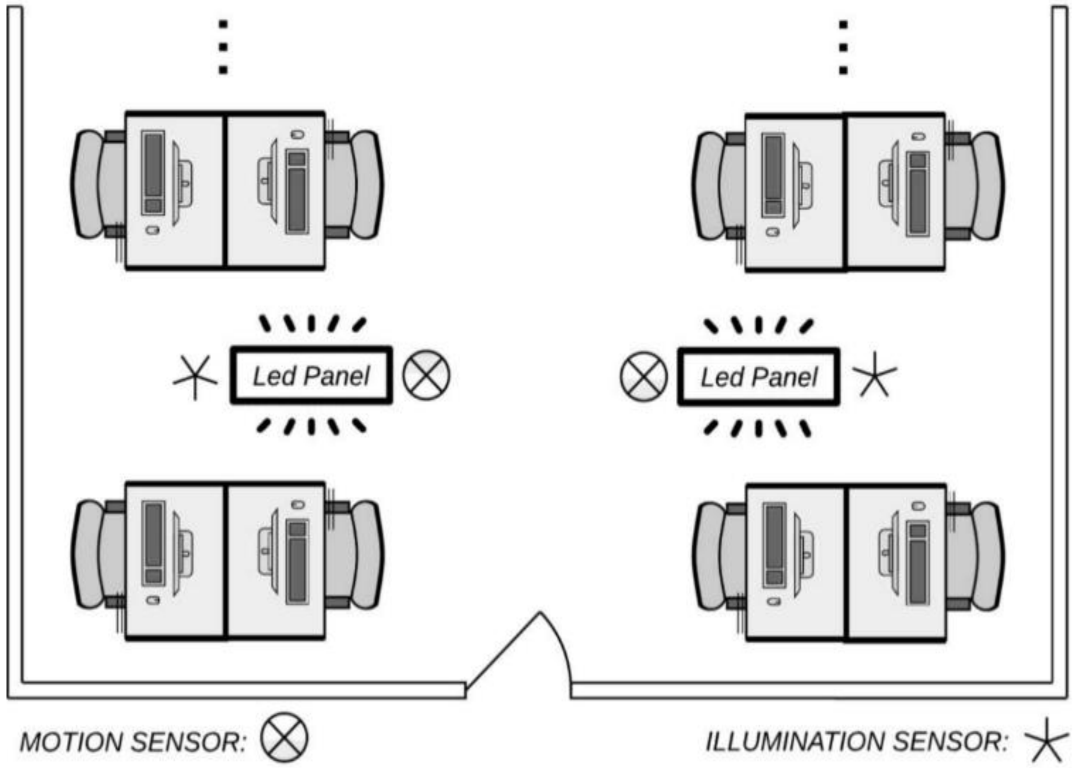


Figure 5.1. Smart LED control system of the office building

5.2.1. Proposed design

The design of the smart led consists of three basic parts as follows:

- A communication part handled by XBee devices (ZigBee standard).
- Sensors part: Motion sensor and illumination sensor for each desk position.
- A PWM controller in order to handle the back convert of smart led.

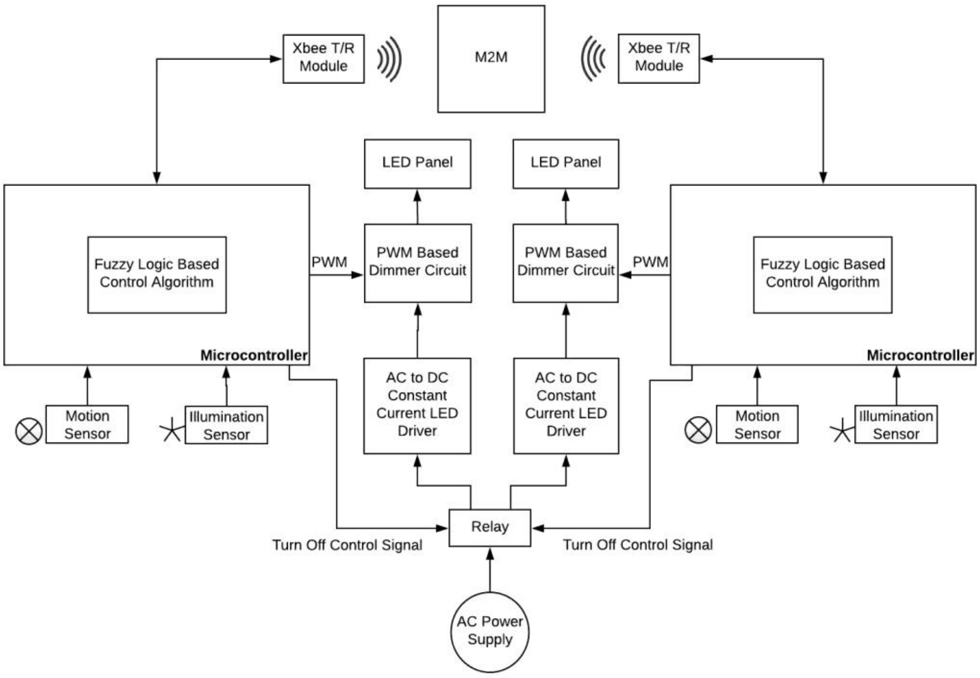


Figure 5.2. Design of the smart LED lighting system

By using M2M communication, the system as depicted in Figure 5.2. and Figure 5.3. could:

- Compare and evaluate the quantity of the total received light.
- Apply some fuzzy logic algorithm to be able to efficiently control the LED light.
- Control the buck converter of the LED light system by generating PWM signal.

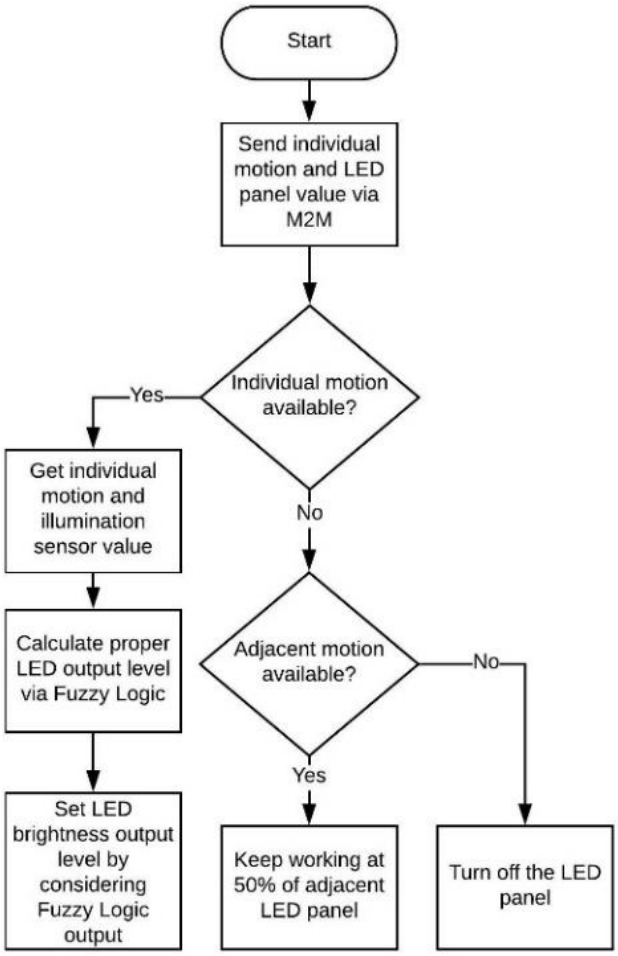


Figure 5.3. Flow chart of presented design and M2M communication

The controller system of the smart led consists of two parts (Figure 5.4.):

- Get data from the illumination sensor in order to make the classification.
- Control the smart LED based on the Fuzzy logic algorithm for each open space.

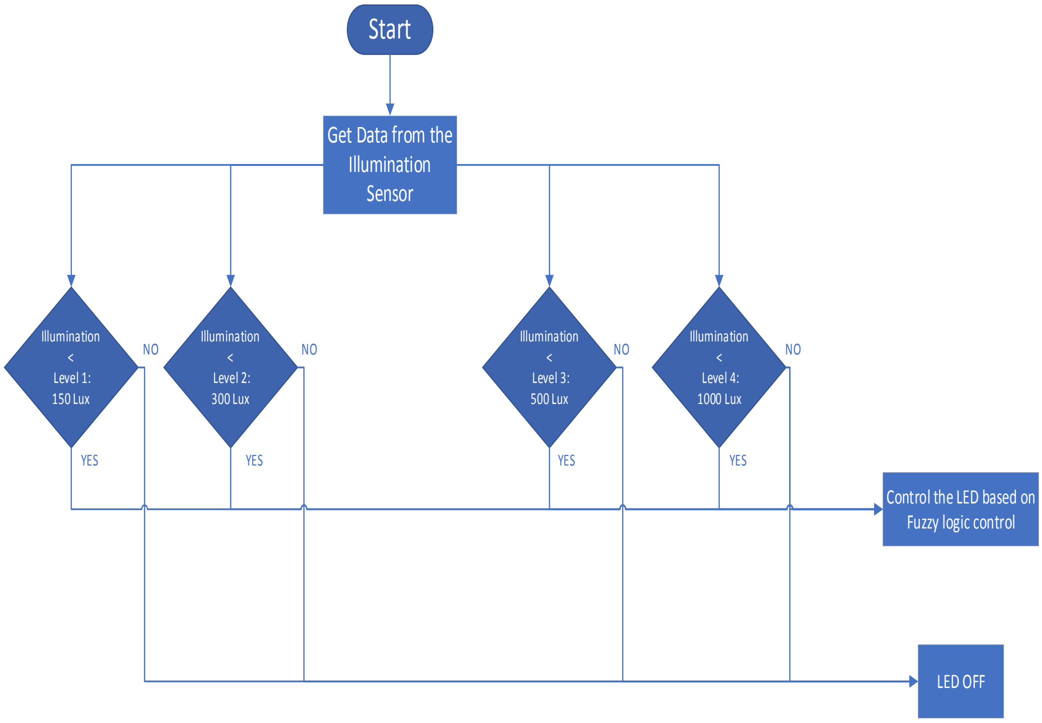


Figure 5.4. Flow chart of the proposed design

The system will neither work in the case of full darkness (Sleeping mode) nor when there is no motion (Empty room). Each LED panel covers one local area in the share of daylight and electric light sources.

5.2.2. Fuzzy logic control

Membership functions of the Fuzzy Logic Control System deal with occupancy in the building and lights (i.e. reflected lights or sunlight) as depicted in Figure 5.5. The figure shows triangular functions of the input variables in three levels while the output variables in five levels.

The characteristic of each level are listed in Table 5.1. The rules of fuzzy logic control system presented in Table 5.2.

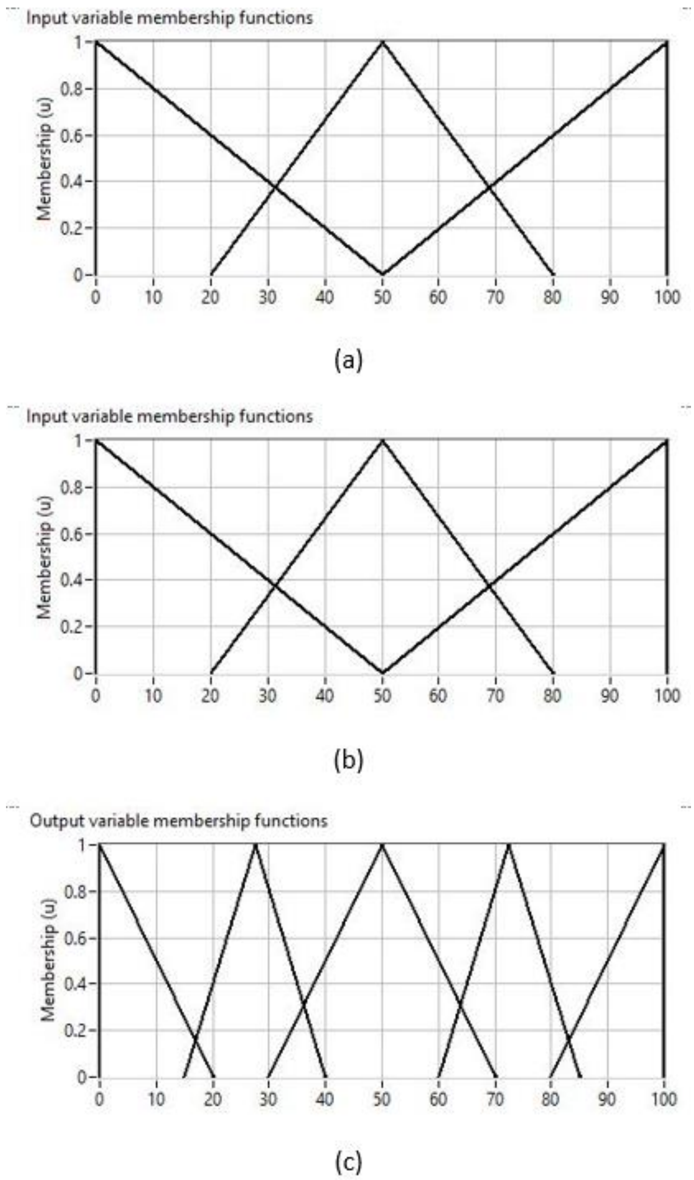


Figure 5.5. Membership function of (a) motion sensor, (b) illumination sensor and (c) the output

Table 5.1. Inputs, Outputs of FLC

Inputs	
Low (L)	[From 0"maximum" to 50]
Medium (M)	[From 20 to 50 "maximum" and 50 to 80]
High (H)	[50 to 100"maximum"]
Output	
Very Low (VL)	[0"maximum" to 20]
Low (L)	[15 to 27,5"maximum" and 27,5 to 40]
Medium (M)	[30 to 50"maximum" and 50 to 70]
High (H)	[60 to 72,5"maximum" and 72,5 to 85]
Very High (VH)	[80 to 100"maximum"]

Table 5.2. Rules of FLC

RULES		ILLUMINATION		
		Low	Medium	High
MOTION	Low	Very Low	Very Low	Very Low
	Medium	High	Medium	Low
	High	Very High	High	Medium

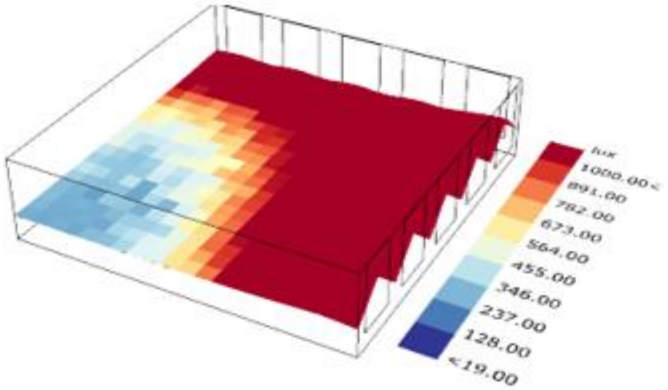
5.3. Simulation Results

The following Figures (Figure 5.6., Figure 5.7., Figure 5.8., Figure 5.9., Figure 5.10., and Figure 5.11.) show the impact of the day light in the all open space of the office building during different seasons and hour of the day.

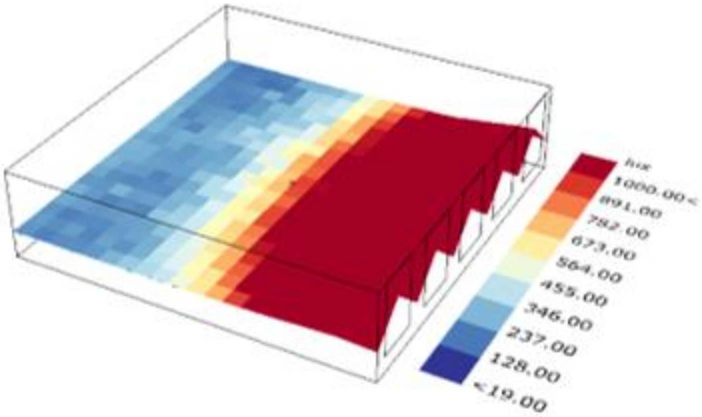
5.3.1. Summer seasons

Time at 8:00 am:

Open space (OS8)



Open space (OS7)



Open space (OS6)

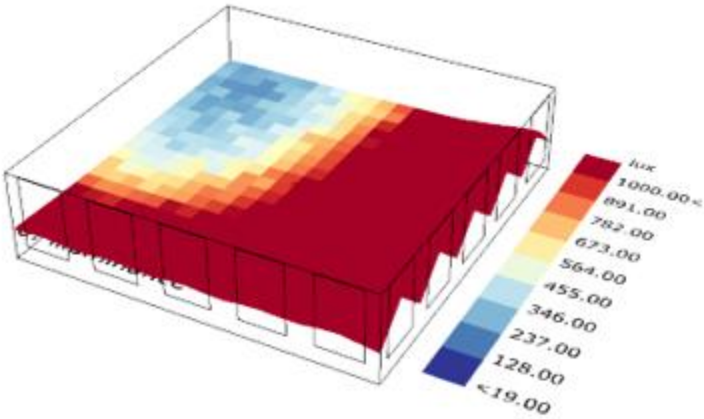


Figure 5.6. Sunlight impact for summer seasons (OS_8_7_6)

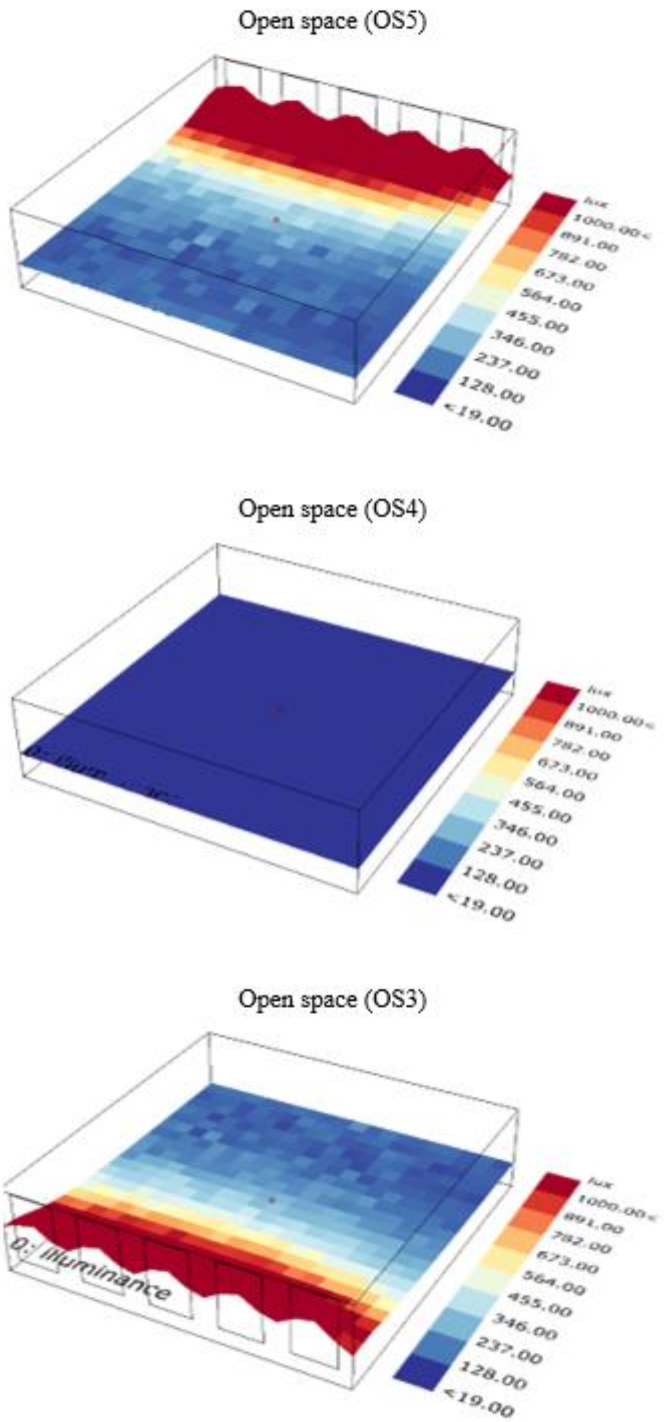
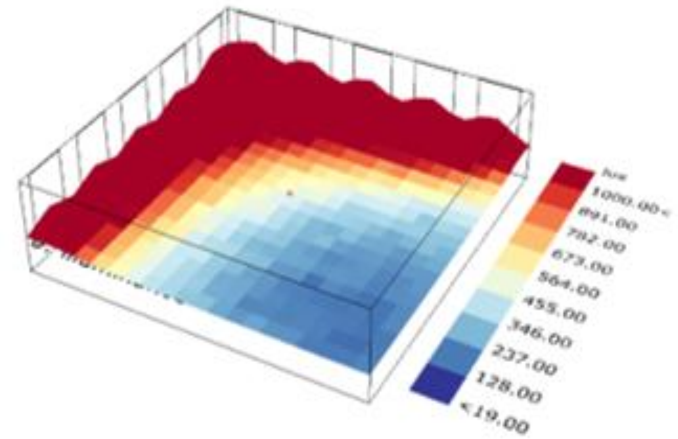
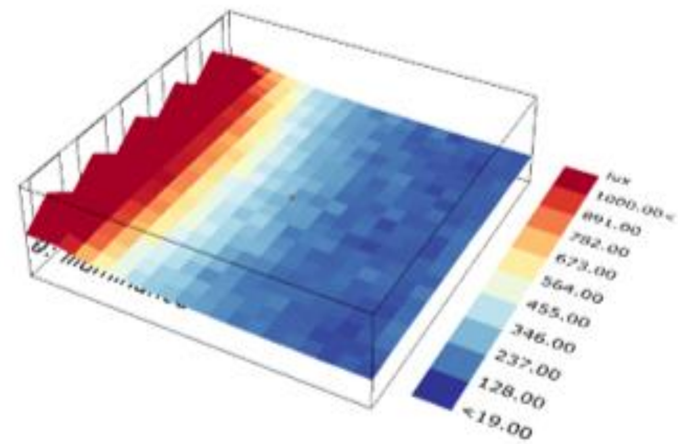


Figure 5.7. Sunlight impact for summer seasons (OS_5_4_3)

Open space (OS2)



Open space (OS1)



Open space (OS0)

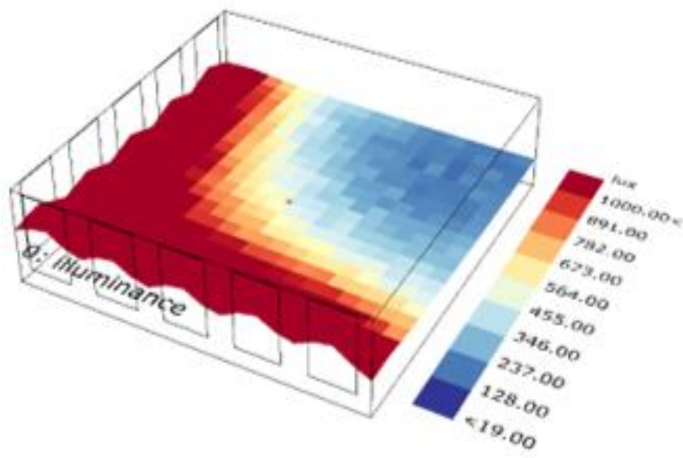


Figure 5.8. Sunlight impact for summer seasons (OS_2_1_0)

5.3.2. Winter seasons

Time at 8:00 am:

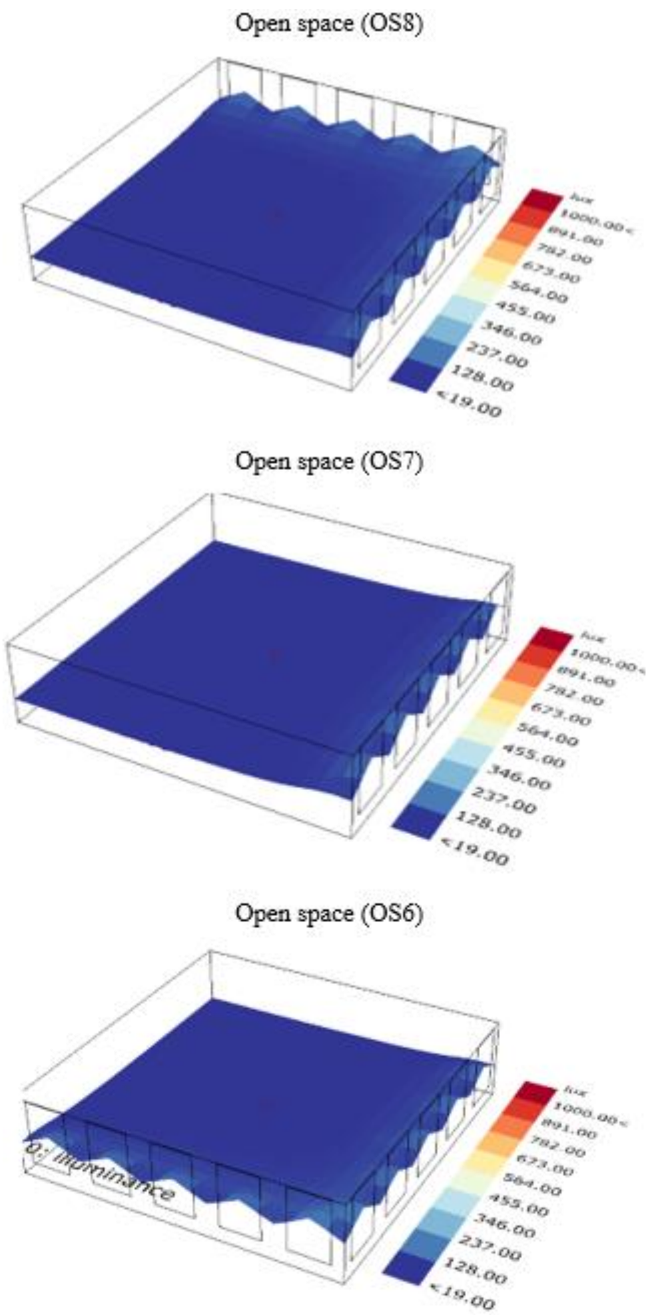


Figure 5.9. Sunlight impact for winter seasons (OS_8_7_6)

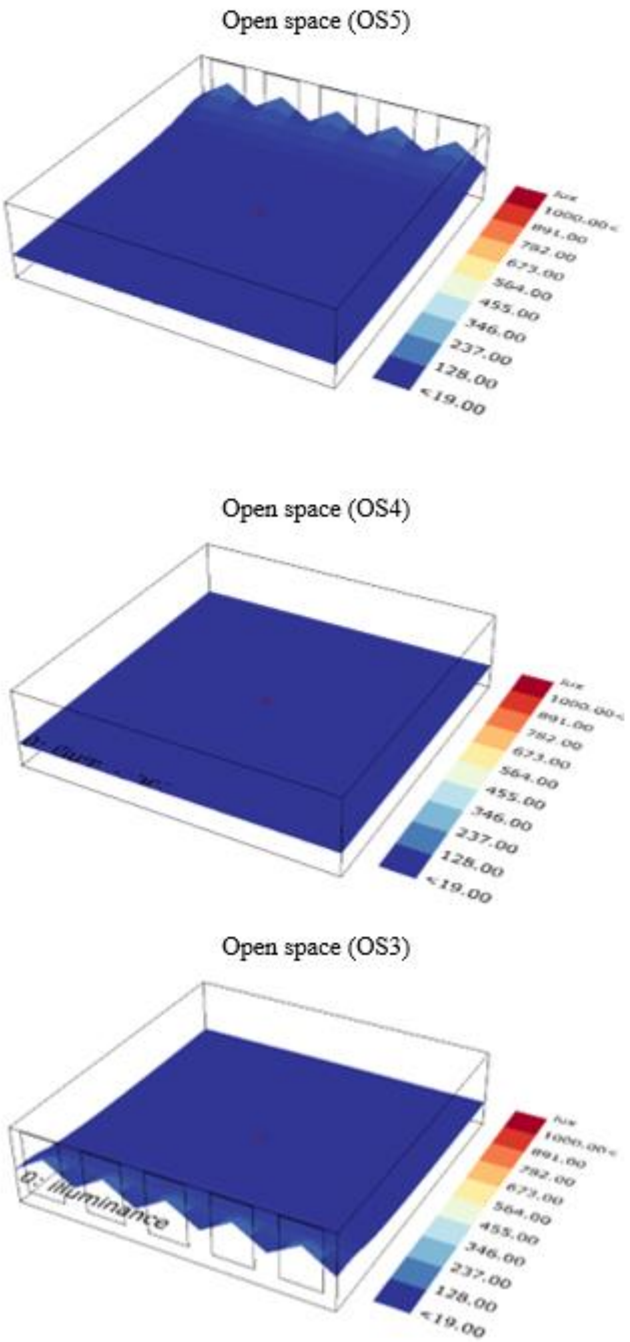


Figure 5.10. Sunlight impact for winter seasons (OS_5_4_3)

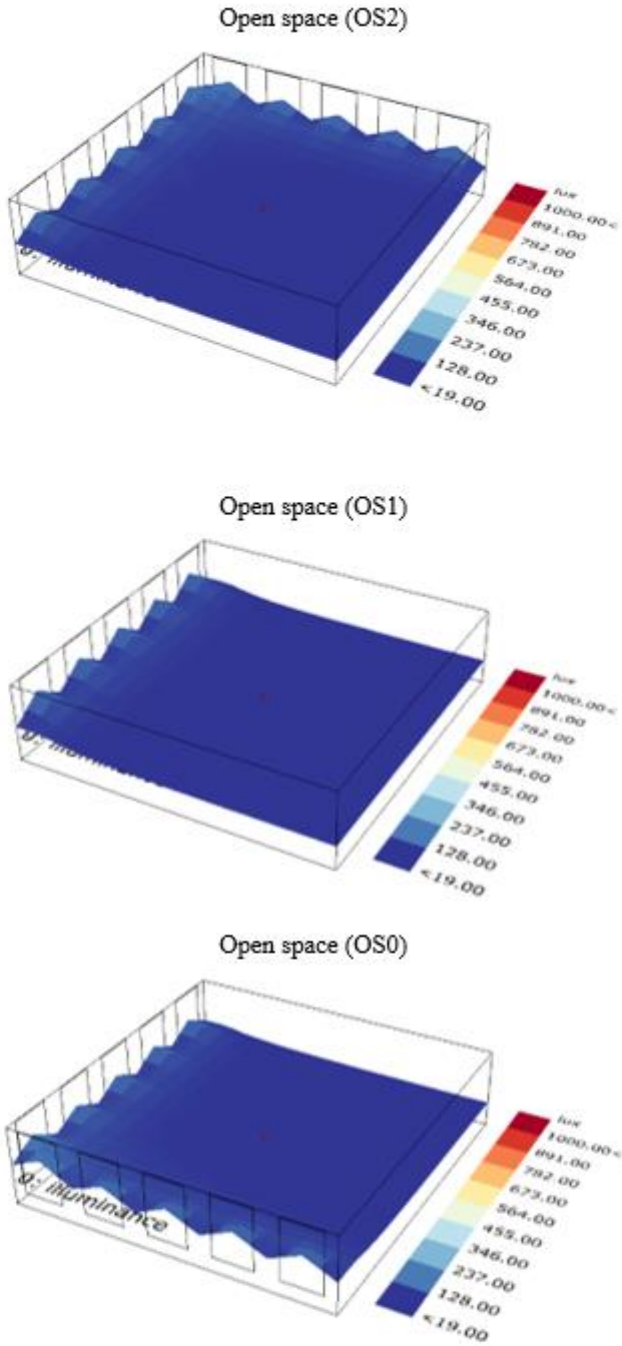


Figure 5.11. Sunlight impact for winter seasons (OS_2_1_0)

The proposed system has been tested for an office environment and results are shown in Figure 5.9. Figure 5.10., and Figure 5.11. The consumed power referring to the brightness level is simulated hourly by using LadyBug tools. LadyBug use validated energy and daylighting tools such as Daysim, Radiance. The results obtained are compared with different threshold level as follows:

- 150 lux: Occupants are working on computer screens.
- 300 lux: Occupants are reading and writing on paper.
- 500 lux : Market spaces where visual effect of specific objects is important.
- 1000 lux : As an example operating rooms in hospitals.

Table 5.3. Power consumption of lighting in the office building

	Power Consomption (KWh)			
Lux Illuminance threshold (Lux)	150	300	500	1000
OS_0	1874.115	1920.346	1973.824	2110.749
OS_1	1926.614	2033.743	2235.864	2718.131
OS_2	1877.214	1931.824	2007.341	2287.758
OS_3	192. 53	1997.327	2100.233	2448.336
OS_4	3838.62	3838.62	3838.62	3838.62
OS_5	1945.258	2115.79	2446.058	3113.518
OS_6	1877.543	1926.469	1982.394	2137.354
OS_7	1939.845	2059.199	2291.948	2780.808
OS_8	1881.967	1939.919	2018.89	2323.538

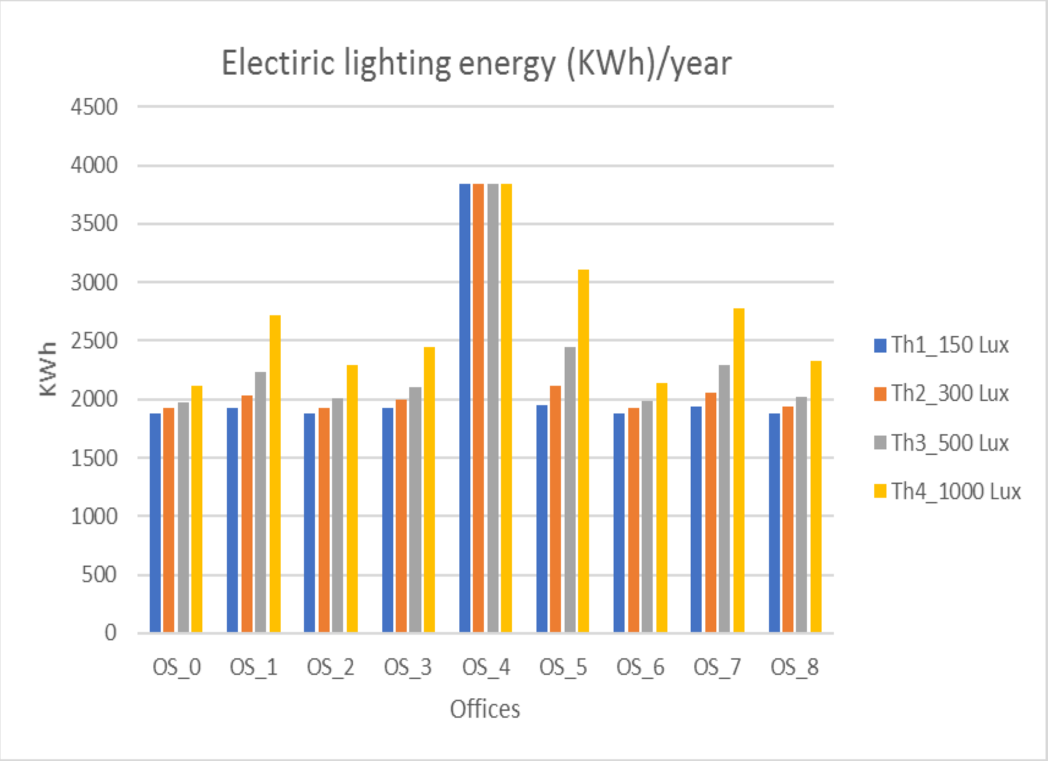


Figure 5.12. Total power consumption for all open spaces in the office building

5.4. Conclusion

In this chapter, new control lighting system has been proposed in order to be installed at separate points of office building. The new design save energy without affecting user comfort. Each unit in the system considers the threshold level of its own specific light sensor and the output level of the adjacent LED panel.

In addition, energy consumption analysis of the proposed system has been performed in comparison with different threshold level of illuminance in term of Lux unit.

CHAPTER 6. OVERALL CONCLUSION AND FUTURE TRENDS

We conducted a deep analysis in energy management for office building. A proof of concept was developed as a first step of the project to demonstrate the feasibility of the design. The large design present more significant challenges to save energy without impacting the thermal comfort of user. Therefore, the performance of proposed strategies was inter-compared to determine the optimal strategy. In other hand, an efficient system design of light control was developed using Fuzzy logic system. The system was simulated and validated. A neat solution is to use machine to machine (M2M) communication between two smart LEDs for autonomic sending and receiving of the LED light as well as efficient movement detection of indoor sunlight. Each unit in the system considers the threshold level of its own specific light sensor and the output level of the adjacent LED panel

In the case of HVAC system side, the comparative results shows that M2M and Enabling/Disabling HVAC system strategies meet the challenge by improving or causing trivial impact on users comfort (i.e, an average Gain of -2.12% and 1.60% for M2M and Enabling/Disabling HVAC, respectively) while saving energy consumption (i.e., an average of around 16% and 14% for M2M and Enabling/Disabling HVAC, respectively). In the case of light control system, the system works for the required performance in accordance with the defined operating conditions. In addition, energy consumption analysis of the implemented system has been performed with different threshold level of illuminance in term of Lux unit.

Future trends for our energy management system design could include:

- Deep learning algorithms instead of fuzzy logic.
- Develop and build a new prototype for an existing office building.

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ANNEX

A1: Building Architecture

All results were obtained assuming complete knowledge of individual preferences and the surrounding thermal environment, and under the assumptions that the building has identical exterior wall resistance values in each zone of the building (corner, perimeter, interior) and identical interior wall resistance values.

The building model considers the following:

- Constructions type of the surfaces, boundary conditions of all the surfaces (such as Ground, and material type of the exterior and interior walls).
- Occupancy schedules.
- Activity schedule(The metabolic rate of the occupants, Heating/Cooling setpoint schedules: depending on the season).
- Lighting schedules.
- Equipment schedules.
- Infiltration schedules.
- Ventilation schedules.
- Loads for internal appliances.

Table 7.1. Thermal resistance coefficients of the building

Form	**Value (m^2K/W)**	**Material**
Exterior wall	2.63	Brick Cavity
Interior wall	1	Gypsum wall board wood frame
Exterior window	0.359	Double paned air-filled window
Floor	1	Insulated wood frame
Ceiling	4	Insulated wood frame

A2: Zone Load Of Building

Setting of zone load are defined as follows:

- Equipment load per area of the conditional space (i.e., 16.79 W/m^2): The device load for one square meter of the flat (Recommended value range from 2 W/m^2 [for just a computer or two in the area] to 16.79 W/m^2 [for an office filled with devices]).
- Infiltration rate per area (i.e., 0.0003 m^3/s per m^2): The estimated rate of the outside air infiltration into the zone per square meter of the flat. The typical infiltration rates based on the exposed exterior wall to the outdoors defined by ASHRAE as follows (0.0001 (m^3/s per m^2 facade) - Small construction;0.0003 (m^3/s per m^2 facade) - Normal construction; 0.0006 (m^3/s per m^2 facade) ; Large construction.
- Lighting density per area (i.e., 11.84 W/m^2): The power consumption of lighting load per square meter of the flat. The typical values range from 3 W/m^2 to 15 W/m^2 for efficient LED bulbs and incandescent heat lamps, respectively.
- The number of people per area (i.e.,0.5 people/m^2): The total quantity of people of people per square meter of the flat at maximum occupancy. The typical values range from 0.02 people/m^2 to 0.5 people/m^2 for a lightly occupied open office and a tightly one, respectively.
- Ventilation per area (i.e., 0.0003 m^3/s per m^2 of the floor): The lowest rate of the exterior air ventilation over the HVAC system into the zone. The typical values range from 0.0002 m^3/s per m^2 to 0.0025 m^3/s per m^2 for spaces like surgery and clean rooms where dust contamination is a major concern.
- Ventilation per person (i.e., 0.0023 m^3/s per person): The lowest rate of the exterior air ventilation over the HVAC system into the zone per person. In effect, an input here will limit the demand-controlled ventilation, where the ventilation over the HVAC system will change depending upon the number of the person.

A3: Web Application

Our web application uses passport ID methodologies with several programming and database techniques to elucidate the work involved in this process. The user can easily request a new passport ID to be confirmed by the administrator or logon directly to the system, the web application has been carefully verified and validated to meet our goals.

- Scope(The web application provides an online interface to the user where they can fill in their personal details and submit the necessary information to the administrator. The administrator uses this web application to manage the system and validate all the requests ensured by the users with a simple manner. Users will come to know their status of demand by email notification in order to join the system).
- Data Flow Diagram(Data flow diagram presents six blocks started from Human user to the last block MongoDB Database.)

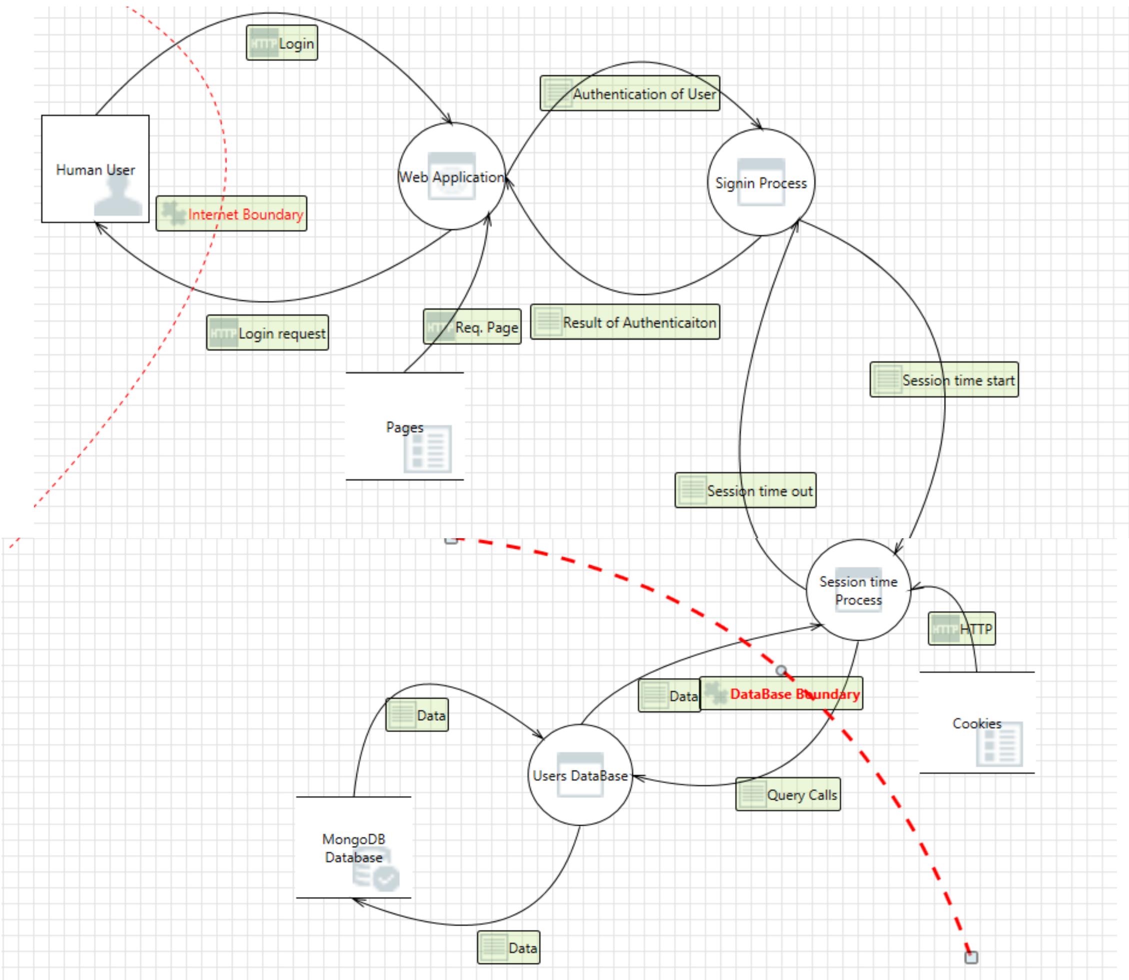

Figure 7.1. Data Flow Diagram

The web application considers only the energy management of air conditioners in the building. The user also has the possibility to monitor the whole system and set his comfort expectation by changing the configuration (the limit of power consumption and the maximum ambient temperature).

Figure 7.2. Monitoring page for the user

Our web application is hosted on static IP address by using **Heroku** platform as a service that enables developers to build, run, and operate applications entirely in the cloud via Node.Js application.

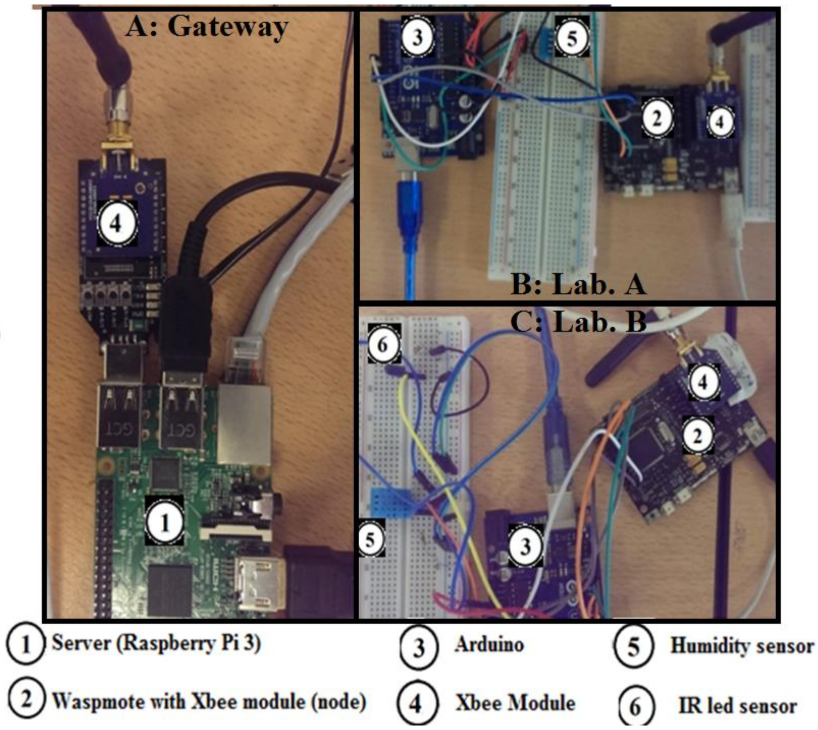

Figure 7.3. Final prototype for IoT web application for managing energy of AC

A4: Daylight Simulation

The following figure show the impact of the day light in the open office for (ON/OFF) test.

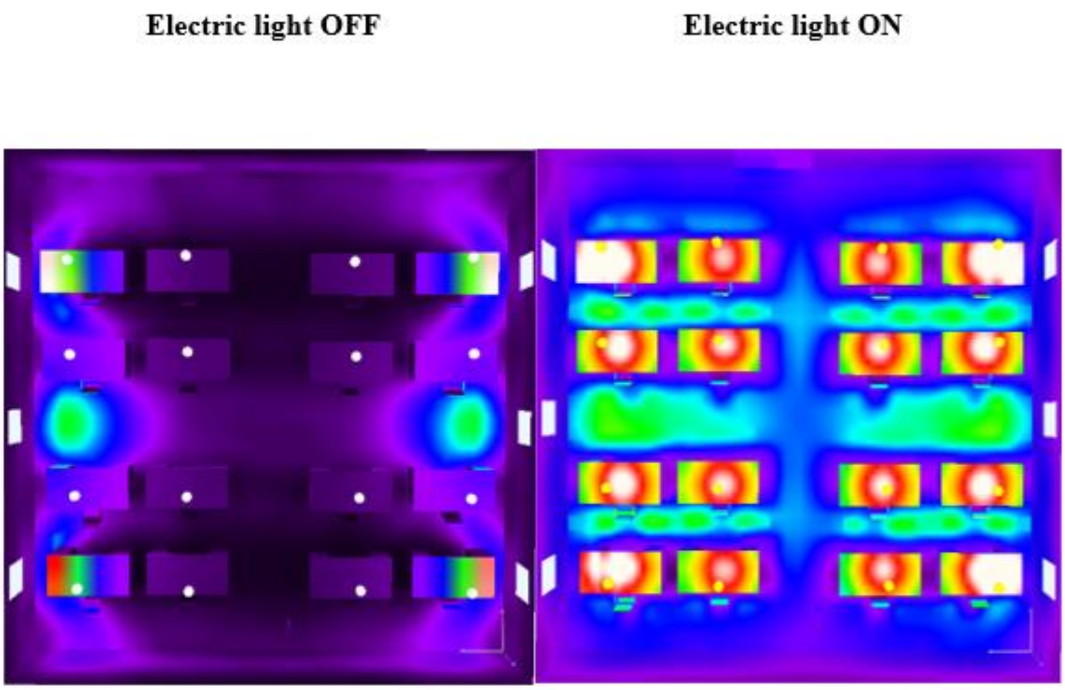

Figure 7.4. Day light impact in the open office

RESUME

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b. Werda I, Chaouch H, Samet A, et al. Optimal DSP based integer motion estimation implementation for H.264/AVC baseline encoder. Int Arab J Inf Technol; 7. Vol.7, No. 1, January 2010.
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2. **Refereed conference publications:**
   a. Chaouch H, Bayraktar AS, Ceken C. Energy Management in Smart Buildings by Using M2M Communication. In: 2019 7th International Istanbul Smart Grids and Cities Congress and Fair (ICSG). IEEE, pp. 31–35.
   b. Chaouch H, Ben Hadj Slama J. Modeling and simulation of appliances scheduling in the smart home for managing energy. In: 2014 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM). IEEE, pp. 1–5.
   c. Chaouch H, Dhahri S, Zitouni A, et al. Low power architecture of motion estimation and efficient intra prediction based on hardware design for H.264. In: 5th Conference on Design and Technology of Integrated Systems in Nanoscale Era, DTIS 2010. 2010. Epub ahead of print 2010. DOI: 10.1109/DTIS.2010.5487604.
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   e. Chaouch H, Werda I, Samet A, et al. Search window impact on H.264/AVC motion search implementation on TMS320C6416 DSP. Int Multi-Conference Syst Signals Devices SSD; III. January 2007.

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