Evaluation of several Air Conditioning and Ventilation Energy Saving Strategies and Technologies in an Office Building

تقييم العديد من استراتيجيات وتقنيات توفير الطاقة في تكييف الهواء والتهوية في مبنى إداري

by

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Dissertation submitted in fulfilment

of the requirements for the degree of

MSc SUSTAINABLE DESIGN OF BUILT ENVIRONMENT

at

The British University in Dubai

September 2020

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Abstract

Managing energy consumption in the building sector become one of the engineers' priority to reducing greenhouse gases GHGs which affect climate and air quality negatively. This is how the scientists, researchers and engineers linked the building design/ system and climate change and air pollution. There is a large volume of literature review investigated the impact of the Heating Ventilation and Air Conditioning (HVAC) system on energy consumption. Besides, how to enhance the HVAC system to be responded to energy saving while keeping indoor air quality and occupants thermal comfort at the acceptable level. As per the previous studies, in a warm climate, the cooling system responsible for most of the energy utilised in the building.

This research examines and evaluates some HVAC strategies and technologies aimed at reducing energy consumption in the office building in the United Arab Emirates UAE. Four scenarios have been created for the summer months and one scenario for the winter months by using the simulation method in the IES VE program. Summer scenarios strategies included the use of programmable thermostat settings in order to reduce energy and shift the peak hour loads while considering occupants thermal comfort. The optimal summer months` scenario achieved a reduction of 43.63% compared with the summer months base case which is 32.1503 MW/h in sensible cooling load. In comparison, Natural ventilation is introduced in winter month scenario in the morning hours only.

To regulate and adjust the window opening with the cooling system, a type of controller is applied under a specific formula. The winter scenario can achieve reduction reaches to 27.22% compared with the winter base case. Looking for consumption per year for the optimal scenario can meet 43.44% compared with the base case per year (summer and winter months) which is 32.5076 MW/h in sensible cooling loads.

The optimal scenario was further upgraded by applying CO_2 controller to obtain more energy reduction per year at the same time maintain the indoor air quality. The CO_2 controller is designed to maintain the CO_2 level at no more than 1000 ppm.

Optimal scenario with the CO_2 controller can implement an 87.5% reduction compared with the base case in sensible and latent load. Both controllers for the CO_2 and the window opening in winter scenario are worked under fuzzy logic which, is (If/Then).

ملخص

أصبحت إدارة استهلاك الطاقة في قطاع البناء إحدى أولويات المهندسين لتقليل غازات الاحتباس الحراري التي تؤثر على جودة المناخ والهواء بشكل سلبي. هذه هي الطريقة التي ربط بها العلماء والباحثون والمهندسون تصميم / نظام على المبنى وتغير المناخ وتلوث الهواء. هناك كثير من الدراسات التي تبحث في تأثير نظام التهوية وتكييف الهواء استهلاك الطاقة الكلية للمبنى. إلى جانب ذلك ، كيفية تحسين نظام الهواء الداخلي والراحة الحرارية للساكنين عند المستوى المقبول. وفقًا للدراسات السابقة ، في المناخ الدافئ نظم التكيف مسؤولة عن معظم الطاقة المستخدمة في المباني. هذا البحث يقيم بعض الاستراتيجيات والتقنيات الخاصة بنظام التهوية وتكييف الهواء في مبنى المكاتب في دولة الإمارات العربية المتحدة. تم إنشاء أربعة سيناريوهات لأشهر الصيف وسيناريو واحد لاشهر الشتاء باستخدام طريقة المحاكاة في استراتيجيات سيناريوهات الصيف والشتاء تعتمد على منظم الحرارة القابل للبرمجة لتقليل الطاقة المستخدمة . حيث يمكن لسيناريو الصيف الأمثل أن يحقق انخفاضًا بنسبة 43.63٪ مقارنة بالمبنى التي تبلغ 32.1503 ميجاوات / ساعة. يتم إدخال التهوية الطبيعية في سيناريو شهر الشتاء في ساعات الصباح فقط. لتنظيم وضبط فتح النافذة بنظام التبريد ، يتم تطبيق نوع من وحدة التحكم وفقًا لصيغة محددة ، ويمكن لسيناريو الشتاء تحقيق تخفيض يصل إلى 27.22٪ مقارنةً نظام المبنى الحالي. البحث عن الاستهلاك السنوي للسيناريو الأمثل يمكن أن يحقق 43.44٪ مقارنة بامبنى في السنة والتي تبلغ 32.5076 ميجاوات / ساعة. تطوير السيناريو الأمثل سنويًا عن طريق تطبيق جهاز التحكم في ثاني أكسيد الكربون للحصول على مزيد من تقليل الطاقة وفي نفس الوقت الحفاظ على جودة الهواء الداخلي. يعمل جهاز التحكم في السيناريو تخفيض الطاقة بنسبة 87.5٪ مقارنة بالمبنى. يعمل كل من المتحكمين لسيناريو وحدة التحكم في ثاني اوكسيد الكاربون وفتح النافذة في الشتاء تحت نظام وهو (إذا / بعد ذلك) .

Acknowledgements

First, I am very grateful to God for guiding me to study master degree.

I would like to thank Prof. Bassam Abu-Hijleh, who supported me through my study to the dissertation stage. Thank you for your advice and patient.

To my mother, her pray and help through my study brighten my way to success, to my father who let me know how to respect the time and hard work to achieve success.

Special thanks to my brother who always there to motivate and help me, and my lovely son with his advice and with his little experience give me the energy to finish this study and to believe in myself.

Special thanks and regards to Sharjah Investment and Development Authority (SHUROOQ) staff who were very welcoming to provide this study with the available data.

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Chapter 1 Introduction.

1.1 Introduction.

Always back to the base of the problem causes to find solutions. If the researchers/ scientists understand where, when and how climate change occurred and its impact on the earth and human beings, will assist them in answering and clarifying the questions and the overall image.

Most of the information in this chapter is from online data to understand and examine the real impact of human activities on climate change. Also, the data demonstrate the connection between building energy and its effects on climate change and identify the reason to conduct this research.

As all the previous researches that were used in this study confirm that the building sector consumes more energy to meet the occupants' needs, in other words, building from the construction stage until the operation through their life span consumes energy. And all the expectation suggested the energy demand for buildings will increase in line with the human population and behaviour. So many investigations and experiments are conducted to find more proper solutions as each building has its specification.

1.2 The CO_2 Emissions and Climate Change.

The CO_2 is greenhouse gases GHG. These gases prevent heat to skip from earth to space which causes an increase in temperature. The CO_2 is occupied a significant amount of GHG. The CO_2 released from human activities, for example, combustion of fossil fuel to get the energy to meet their needs, energy which needed for electricity and transportation. After transportation, electricity occupied 2nd place in 2018 as one of the primary resources of the CO_2 which is around 32.3% of overall US CO_2 releasing. And 26.3% of GHG.

Figure 1.1 shows the ratio of the CO_2 released in the US in 2018, CO_2 takes around 81% compared by other gases that release from human activities not only combustion but also manufacturing, seeding and waste management. However, the CO_2 can naturally be taken from the atmosphere to create a balance; this can happen by plants. However, when the amount of CO_2 exceeds the capability of nature to observe it, this will affect the natural balance and cause GHG. (United States Environmental Protection Agency (EPA) 2018).

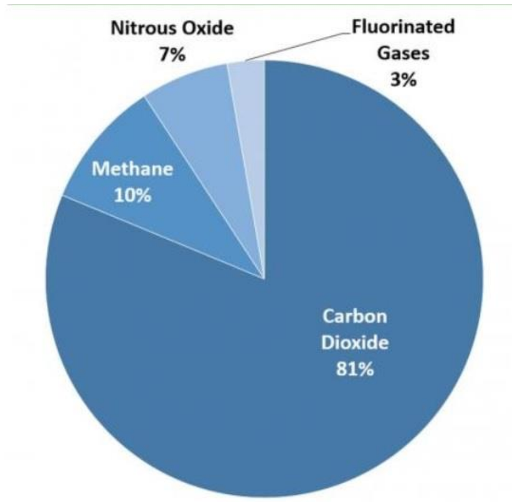

Figure 1.1. The amount of GHG in the US in 2018.(United States Environmental Protection Agency (EPA) 2018).

In UAE and as per United Arab Emirates Ministry of Climate Change and Environment (2017) plan, the amount of carbon dioxide has been raised since the nineties from 74.4 MtCO2e in metric tons unit to reach 203.7 MtCO2e in 2015.
What mentioned above cause climate change, As per NASA Global climate change (2020), The earth temperature has increased nearly to 0.9 ^{o}C from the 19th century due to the growth in human activities. The last 35 years witnessed the boost in temperature and from 2014 till now registered as the hottest years.
However, the obvious reduction was noticed in CO_2 releasing in 2020 compared to the year 2019. The main reason was due to the worldwide shut down in most of the industrial and manufacturing activities because of COVID-19 pandemic. This reduction is relating to the lack of demand for energy usage. As per the recent investigations and studies, generally, the first quarter of 2020 witnessed a 5% reduction in the CO_2 releasing compared with 2019. This is the first significant reduction since the world war ll. The most countries that examine the CO_2 lowing, are those who suffered more from COVID-19 like China, Europe and the US. The amount of CO_2 predicted to decrease more for the rest of the year compared to 2019 to get to 8%. Figure 1.2 illustrates the CO_2 reduction in gigatonnes from 1900 to 2020. (IEA Global Energy Review, IEA, Paris 2020).

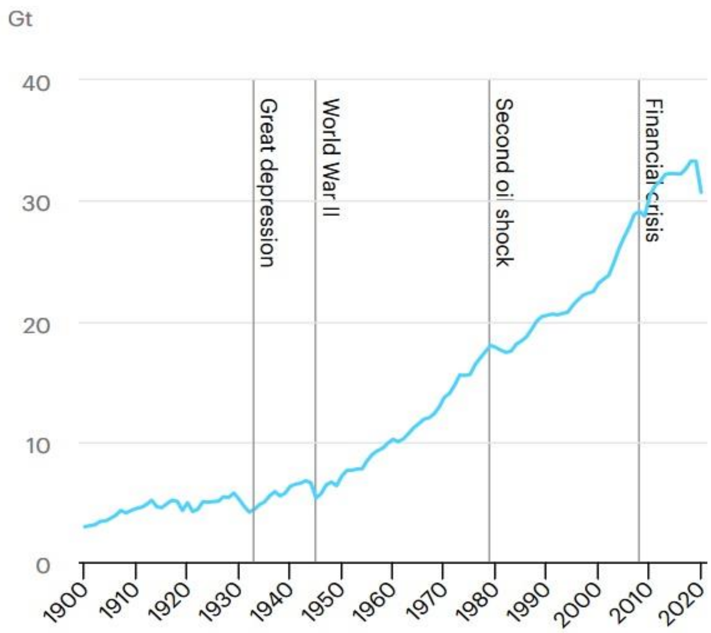

Figure 1.2.The CO_2 reduction in gigatonnes. (IEA Global Energy Review, IEA, Paris 2020).

One study by Berman & Ebisu (2020) conducted an actual measurement for air quality during COVID-19 in the US. The research focused on particulate matter $PM_{2.5}$ and Nitrogen Dioxide NO_2, which is GHGs. The examination carried out from (8th of January- 21st of April), and they compared the results between the years from (2017-2020). The data was from openAQ (2020), which is an organisation target to enhance the outdoor air quality by rising online air measurement around the world. And for the previous years, the data was collected from EAP. To be more accurate, they divided the country into: the district with early shutdown; district with the late shutdown; and ruler or urban. Overall, the lowering was clear for both pollutants as: for NO_2 the statistically significant was 25.5% also for the $PM_{2.5}$ the lowering was statistically significant more for urban and the early shutdown district as some samples could not match the statistically significant. Both results were during the COVID-19 compared with the previous years (2017-2019).

1.3 Building Energy.

Referring to the above section, which is about CO_2 emissions, this section discusses the reasons and solution for this problem when it comes to the building sector. First, identify the source of energy that is using to generate electricity. Most of the energy source is a fossil fuel, as per U.S Energy Information Administration (eia) (2020), for example in US 62.7% of electricity provided from the burning of the fossil fuel, natural gas occupy 38.4% from it and coal 23.5% in 2019. Also, 17.5% is a renewable source like hydropower, wind, solar, biomass and geothermal, as wind occupies the highest per cent which is 7.3%. And 19 .7% is from a nuclear power plant in 2019.

However, burning of natural gas can release less CO_2 compare with coal which responsible for 65.8% of CO_2 and provides electricity of 28.4%, and 34.1% electricity from natural gas and 16.7% for renewable energy in 2018. (United States Environmental Protection Agency (EPA) 2018).

In UAE the main source for electricity is natural gas as it is about 100%, in uncommon situations when there is a high level of demands like in summertime and inadequate level of natural gas, the heavy oil and diesel are utilised. Also, lower than 1% diesel is applied as off-gride; besides, solar energy provides 100 MW from Shams1. (IRENA 2015 P.10).

Second, understand the connection between energy used in buildings and where the most loads occurred. Figure 1.3 shows the energy sources and the specific energy consumption and loss. All the buildings have their internal loads relating to the function and number of the occupants with essential requirements to meet their needs. For example, the HVAC system to meet their thermal comfort. However, the building exposes to extreme conditions like solar radiation, air temperature, Relative Humidity and infiltration, which assist in the increase/decrease the building mass temperature and disturb the indoor comfort level. The design challenge is how to balance and control the internal loads with the outside weather condition.

As per IEA fuel and technology cooling (2020), the required for cooling become two times more than in the year 2000. The cooling system consumption considered in 5th of the overall building energy usage in the world; in other words, it uses 10% of the total energy. Accordingly, the HVAC system design required strategies and advanced controllers to maintain the air temperature, humidity, airflow and quality. As per figure 1.3, which illustrated the controllers function in the building system.

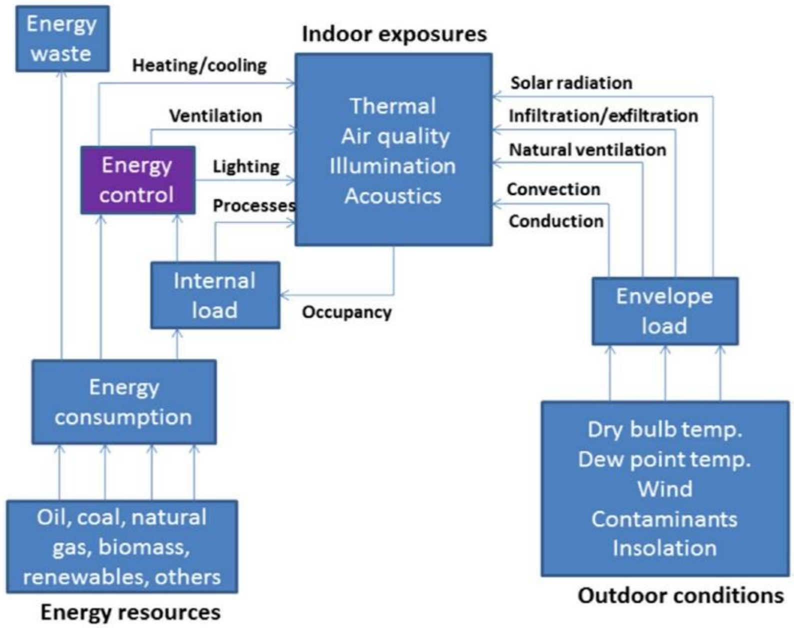

Figure 1.3. Building energy digram. (Atam 2017).

One study by Cao, Dai & Liu (2016) demonstrated that building function process consumes most of the electricity, and the HVAC system is responsible for 50% of the total building energy in economically advanced countries where there is an awareness about how to reduce building energy. So, it is beneficial to design strategies for minimising HVAC energy use. One approach is the passive design which deals with building direction, material, insulation and glazing technologies. Another method is active strategies like controlling the energy that consumes from building service as per figure 1.3. These two methods (passive/active) deals with the building itself without looking to the type or source of energy that the building use, this led to planning zero energy building (ZEB), additional to the above methods using renewable energy as the main source of electricity.The researcher here identified the ZEB as the method which connects between the conventional green strategies and renewable energy.

While, IRENA Heating and Cooling (2020), suggests that even with the development of renewable energy still, the passive and active methods are fundamental to minimise the energy consumption for the building. For example, insulation materials, glazing system and using monitors for building services like advanced air temperature monitors (thermostat), in general, manage the electricity usage. Building energy is explained in details in the next chapter, which is the literature review.

1.4 Research Keywords and Motivation.

The main focus of this research is energy reduction by examining some strategies and technologies in the HVAC System in office buildings in the UAE. It studies the decrease in the overall cooling loads and the peak time loads. The evaluation was done through programming the thermostat in different setpoints for working hours and out of working hours. Study building function and occupancy behaviour is the main key to find out a variety of scenarios in the Summer and Winter seasons.

Papadopoulos et al. (2019) conclude that this type of adjustment on the building is relating to the people themselves. It shifts the HVAC system to further capable one. This modification contains many steps, for example, programming and resets the thermostat and introduce the natural ventilation to the spaces by controlling the window opening.

These uncomplicated steps have less capital intensive like the thermostat could be programmed easily as per the space function and people behaviour. Compared to another type of building modification which concentrates on physical changes like building materials. As this type of building modification is difficult, needs more time and is costly. Similary, Sun, Gou & Lau (2018) noted that this type of building modification might be implemented under the automation program in building services. For example, the monitors in the HVAC system. These improvements are fundamental to minimise overall building consumption.

In this research, the scenarios were estimated not only under energy saving but also thermal comfort for the occupants and indoor air quality IAQ for the office building. However, the greater focus for the IAQ is the level of the CO_2 concentration on applying and studying the CO_2 controller /Demand Control Ventilation (DCV).

According to Merema et al. (2018), many research papers on DCV pay attention to its effect on IAQ and the amount of airflow rather than on the energy consumption of the system. In addition, no research has been found that test the impact of the DCV on sensible and latent loads in the HVAC system, and relating to a hot, humid climate like Sharjah. So this study examines the effect of the CO_2 controller on IAQ and energy-saving relating to the sensible and latent loads for the HVAC system in the office building in Sharjah**,** Besides to the programable thermostat.

Overall, this study contributes to this growing area of HVAC system performance. Firstly, resetting the thermostat schedule and understand its programable method. Secondly, applying CO_2 controller, and examine its method and strategies in the HVAC system energy-saving, besides, controllers which work with the window opening to introduce natural ventilation to the spaces. So the focus on how the controllers can work to achieve a significant reduction on energy. The absence of research in understanding and achieving these strategies and technologies in the UAE and prove its assistance in energy-saving is the main key to conduct this research, particularly in office buildings.

According to the literature review, office systems consider energy waste as most of the studies focuses on how to maintain the HVAC system in these types of building. The office buildings witness fluctuating in internal gains, like the number of employees and the unawareness of the employees to manage the cooling/heating system relating to their needs, this may be the main reason to the energy waste. As per Arab forum for Environmental and Development (AFED) (2012 P. 21), and as shown in figure 1.4, the suppositional electricity consumption in the offices as the cooling loads dominates on using of the electricity. So do/can these strategies and technologies maintain the energy using and indoor air quality in office buildings. The evaluation of these techniques is essential to answer this question.

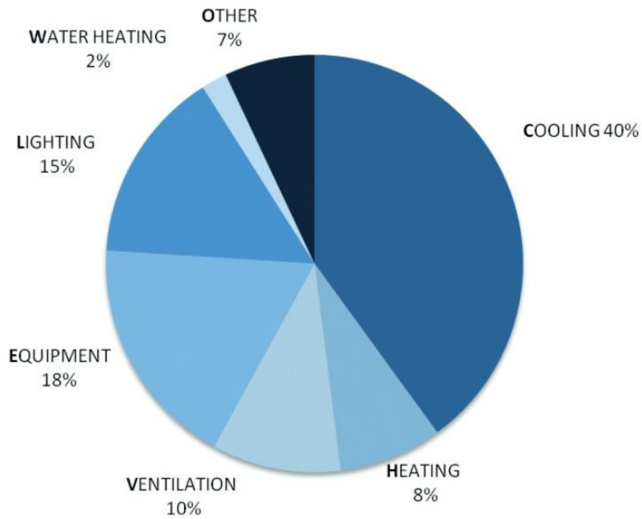

Figure 1.4. Energy consumption in the offices. Arab Forum for Environmental and Development (AFED) (2012 P. 21).

1.5 Aims and Objectives.

The main aim of this study is to understand and simulate the effect of different HVAC control strategies and the resulting energy savings and load shifting from the peak hour. These strategies deal with the air temperature setpoint and two types of controllers. One type is to maintain CO_2 level inside the spaces, and another type is to regulate the window opening for natural ventilation. In order to systematically assess these strategies, the following objectives have been identified:

- To examine different thermostat setpoints and programs for the HVAC system;
- Study the base case which is an office building in Sharjah and upon that;
- Applying different scenarios for the summer season through thermal profile for the spaces taking into consideration thermal comfort for the occupants;
- Introduce natural ventilation in the winter season scenario by applying a specific type of controller and understand how this type of controllers working relating to open/close the window.
- Conduct a comparison between the scenarios to find the optimal one for energy-saving and shift the peak hour load.

- Upgrade these strategies by applied CO_2 controllers to investigate and understand the function and the impact on the indoor air quality IAQ and building energy, particularly on sensible and latent loads.

1.6 Research Outline.

This research has divided into six chapters. The study outline can be listed as below:

- The first part deals with the introduction. Which explains the reason behind this research, and why these types of studies are conducted. Overall, it proposed the main point of this research.

- The second chapter reviews the previous studies that have a direct connection with the HVAC system, indoor air quality and energy consumption which is the primary point of this research. This chapter illustrates in details and gives an idea about the dimension of this research.

- The third chapter is concerned with types of methodology that have used in the previous studies for the HVAC system. This chapter is important to assist the researcher in identifying the appropriate method. As the type of the method, time and the cost are essential in finding the accurate answers/ solutions for the introduced problem in this research.

- Chapter four deals with the problem and the suggestions by giving an example which is an office building in Al Qasba canal in Sharjah city UAE. And by using the chosen method with available data.

- Chapter five is represented and discussed the results. It introduces the findings in details and the reasons behind them. This chapter assists the researcher to find the optimal solution.

- Chapter six gives the overall concept and findings of this study. Also, it discusses future suggestions that might assist in upgrading this study to the next level.

Chapter 2 Literature Review

2.1 Introduction.

This chapter discusses some parameters that were used in previous studies relating to the HVAC system. However, several relevant works of literature can be found through this research because of the large volume of the HVAC system studies. Most of the studies agree that each building has its requirements to maintain and control the HVAC system referring to the internal loads and building function.

There is a large volume of published studies describing the strategies and technologies of pre-cooling and thermostat setpoint by implementing programmable and algorithm methods. In other words, increase the thermostat setpoint or apply schedules to the thermostat. The most parameters that were used in the research papers are:

- Temperature setpoint Combined with thermal comfort;
- Indoor ventilation level combined with indoor air quality (IAQ), particularly the CO_2 concentration and the method of the controllers.

Both the above parameters aim for energy-saving and indoor environmental quality.

This chapter is divided into three parts; the first part deals with the cooling system; the peak load problems in the UAE and around the world; and programable thermostat which is active strategies as a solution. The second part is about the ventilation system and controllers like mix mode strategies and demand control ventilation (DCV). And the third section is about how to maintain indoor air quilty and thermal comfort with active strategies.

2.2 Cooling System.

A considerable amount of literature has been published on the HVAC system in the buildings. However, in this section, the general concept for the HVAC system was discussed. The listed below are the essential terms to understand the working methods for the cooling system:

- Sensible cooling: which is responsible for decreasing the indoor thermal level without affecting the level of the moisture in the air.
- Dehumidification or latent cooling: which is responsible for taking off or minimise the moisture from the indoor air.

There are many types of HVAC systems. Air-water system is the most applied one in the present HVAC system. Figure 2.1 shows one design of the air-water system, which contains: air handling unit (AHU), Chillers/ boilers and fan coil unit (FCU). The water and air are separately transferred to the rooms. The water pipes from the chiller pass through the FCU, and the air moves through ducts to the spaces. This system assists in maintaining indoor air quality and thermal comfort for the occupants. (Grondzik&Kwok 2015, PP. 426, 546,548 & 550).

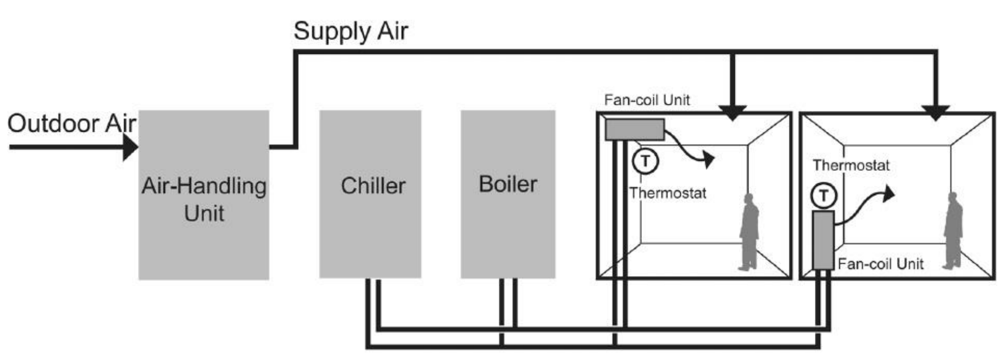

Figure 2.1. Air- water system. (Grondzik&Kwok 2015, P.550).

AHU is an integral part of the ventilation system as the primary function of the AHU is supplying cold fresh air inside the building if it installs on the building roof. Some systems designed to have one AHU to circulate the fresh air in the building, others have more than one AHU mainly in the modern design building to ensure the level of indoor air quality for each space. The AHU depends on the chiller to cool down the fresh air, but it has a fan to pull the air in inside the unit. (The engineering mindset 2017).

Also, One study by Shea, Kissock & Selvacanabady (2019) Pointed out the work method of the AHU before examined the energy-saving suggestions for this unit. In the US, AHU is basically applied for most of the buildings as it might serve different zones. AHU contains cooling coils of water comes from the chiller; this coil works as heat exchanging with air coming from outside. Currently, Most of the buildings are using Variable air volume (VAV) instead of constant air volume (CAV) as a method of air distribution to the spaces. The VAV regulates the indoor conditioned airflow according to the number of people and their thermal needs. The air from the spaces (return air) might combine with outside air in the AHU before crossing the cooling coil, that assists in minimising the energy consumption as the return air still has less temperature than the outdoor air temperature. Overall the AHU is vital to the ventilation system of the building, which affects the IAQ and occupants health and productivity. However, referring to the introduction chapter section Building energy and according to Shea, Kissock & Selvacanabady (2019), the cooling system is the most significant section in the commercial buildings in the US that consumes more energy than other sections. About 18% of the overall US energy goes for commercial buildings only. About 44% of that percentage goes for the cooling system. While Png et al. (2019) pointed out referring to previous studies, Singapore buildings use around 51% of gross energy and a considerable part utilises by the cooling system. Ming et al. (2020) demonstrated that buildings in economically advanced countries use more than 40% of gross energy; however, emerging countries expect to use more than that portion of energy in the year 2020, 50% of that energy consumed by the HVAC system.

2.3 Cooling System Consumption in UAE and the Peak Load.

Further to the above section and, according to Salameh et al. (2020), UAE considers in the fifth place in energy using per capita compared with the other countries. Domestic and multifunction sectors are responsible for exhausting more electricity, as increasing the outside temperature with the Relative Humidity in UAE during the year cause to use more energy. The cooling system in the UAE employs around 36% of the power. (Demand-side management for electricity and water use in Abu Dhabi 2009 in Salameh et al. 2020).

In Abu Dhabi, the cooling system uses 41.7% from building electricity and 58.2% divided for lighting, water heater and other equipment. (Smith 2012 in IRENA 2015 P.17). The cooling system percentage might increase to reach to more than 60% of the building energy.

Dubai Electricity & Water Authority DEWA (2020) suggests that the peak demand hours in Dubai are from 12:00 -6:00 pm.

Also, according to DEWA, the cooling system consumes around 60% of energy during peak hours compared with other appliances. (Gulfnews 2016).

However, the most peak hours in Sharjah city during summer months is from 2:30 pm to 3:30 pm as per Sharjah Electricity & Water Authority SEWA(2019). The peak load occurs because of increasing electricity demand at that time. Dewa suggests some procedures to reduce electricity demand during the peak load, for example:

- Modify the air temperature setpoint if raise one degree for the air temperature setpoint, may achieve to save 5%;
- apply a regular schedule for the thermostat which can monitor the cooling system working time;
- when the cooling system is on trying to reduce the level of the infiltration;
- by changing the cooling system equipment after their life span, which is ten years with an advanced system can achieve around 25% saving in electricity:
- using natural ventilation in the winter season.

The Regulatory & supervisory bureau RSB for electricity and water in Dubai conducted research on the type of cooling system that is using in Dubai and its electricity utilisation. The research information was gathered from the suppliers and scanning the type of cooling system in existed buildings and from DEWA. Figure 2.2 shows the percentage of the used type in Dubai. Also, figure 2.3 shows the electricity using for different types of cooling system.

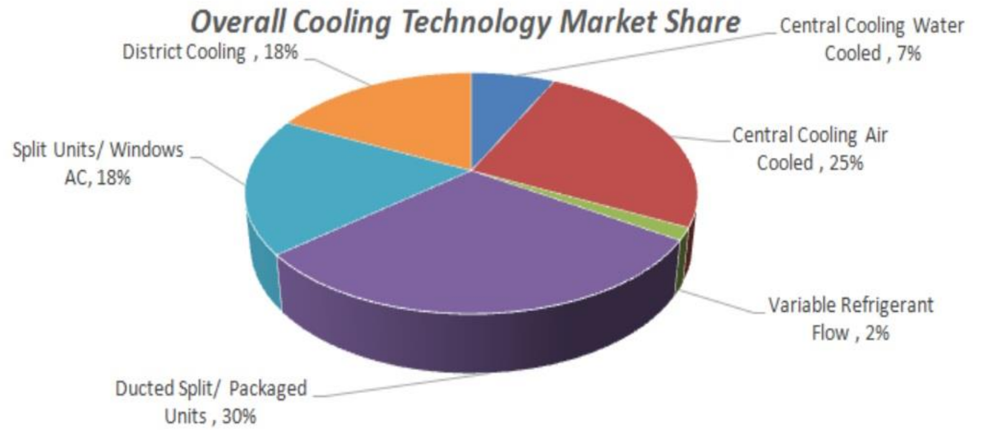

Figure 2.2. The type of cooling system in Dubai. (RSB for electricity & water 2019).

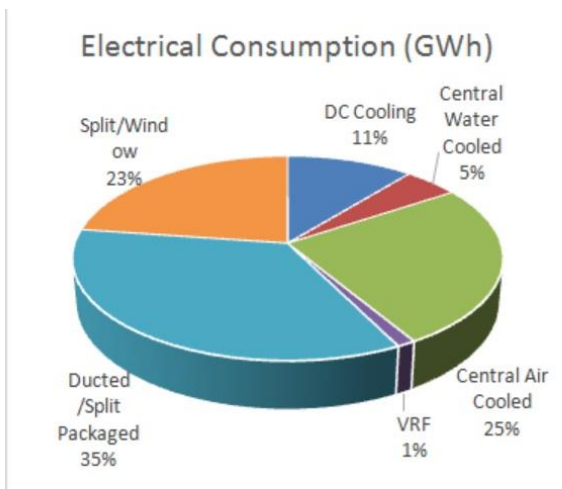

Figure 2.3. The electricity using for the cooling system in Dubai in (GWh). (RSB for electricity & water 2019).

On the other hand, Turner, Walker & Roux (2015) defined the peak loads as the ultimate or highest level of using electricity in a specific time from many consumers. Generally, the peak load takes place in the summer months and during the day time between 16:00 to 20:00 when the occupants back to their home and turn on the cooling system. To cope with this problem, the usual solution is to increase the ability of the power plants, which lead to more cost and more CO_2 emissions and other harmful gases. In the USA, many firms are encouraged to propose incentives option to the users. The proposal is to decrease the electricity price before the peak hour which promotes the users to lower the thermostat setpoint and during the peak hours the user could raise the thermostat setpoint to save the cost and minimise the peak loads as the internal spaces are already cooled down. This procedure called pre-cooling by using different setpoints with different duration of the pre-cooling time. It works to cool down the building mass, which is in this study timber frame, before it being occupied that transfers the loads from the peak hours. However, this active process works better with the passive design of the building like shedding devices, apply significant insulation or use thermal mass techniques.

(Lechner 2015, P.514, 591) Suggested some solutions regarding the thermal mass and pre-cooling. For example, the insulation, thermal mass from outside to inside can slow down the heat movement to the internal spaces. Also, It is significant to increase the time lag, which is the variation between the highest level of the temperature for in/outside. As, by using pre-cooling before the peak hours, assists in cooling down the thermal mass and turn off the cooling system in peak hours for a while because of the thermal mass specification in storing heat. Figure 2.4 shows an example of the time lag during the day.

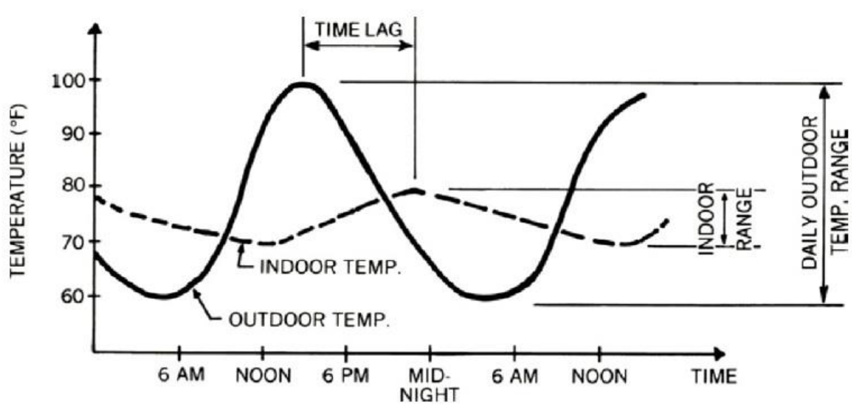

Figure 2.4. the time lag during the day. (Lechner 2015, P.514).

While Alibabaei et al. (2017), examined the pre-cooling with active and passive strategies in a residential building in Canada. The researchers found the thermal mass works better in the heating season than the cooling season by running simulation in TRNSYS. Also, it works better in typical cold and hot weather than in quite cold and warm weather. In summer season the strategy was to turn on the cooling system before peak hour, as it assisted in cooling down the spaces before the peak hours. They assumed that peak hours are between 11:00 am to 16:00, and pre-cooling began at 10:00 am. Overall, saved thermal can works better with types of thermal mass materials, the ratio of opening to the opaque surface and the direction of the building.

2.4 Programmable Thermostat and Strategies.

Thermostat contains monitors and sensors together in one instrument. There are many types of monitors in the HVAC system, referring to the working method. One example is a digital monitor; this type might allow the occupants to modify the thermostat program to meet their needs during the day. So the working process depends on the input variables. Another type works by setting two situations, for example, programmable thermostat according to the occupied or unoccupied room or set the main and back temperature like one during the day and other during the night. Also, some thermostats have a separate timer inside it. (ASHRAE Handbook 2017).

According to Afram & Janabi-Sharifi (2014), generally the monitors in the HVAC system may be divided into four main classes:

- classical controllers which are typical on/off method;
- Hard controllers which are programmable method as per the space requirements like airflow temperature. This type assists in reducing electricity use in the HVAC system ;
- Soft controllers which are fuzzy method depends on if/then like demand control ventilation. This type supports energy-saving and secures the indoor air quality.
- Hybrid controllers, which combine both soft and hard method.

However, most studies focus on the time people spending inside relating to the space function. Study occupants' patterns and the space function might assist in understanding the internal loads to find the strategies that meet the space requirements like the thermostat setpoint and the operation program. Some studies suggested installing a camera to recognise the number of occupants and their behaviour inside the spaces.

Nikdel et al. (2018) pointed out, some studies evaluated that 39% of the cooling and heating electricity in the USA goes lost because of: cooling/ heating vacant interiors, or spaces that are using lower and upper heating setpoint than required, and areas that have a certain level of infiltration. The researchers argued that serious actions should be taken to minimise electricity wastage. As some previous study suggested to apply a programmable thermostat to space according to their function. Nikdel et al. (2018), examined some strategies in the office building in different climate in the USA by using two types of the thermostat. One thermostat is programmable, and other depended on the time that employees used the spaces. The first pattern was the thermostat working continuously even during the night and holidays, which is the constant mode. The second pattern was changing the thermostat setpoint as per day and night, in the cooling mood increase the setpoint during the night and the weekend. The third pattern was depended on the number of employees in the space.

Figure 2.5 a shows the first pattern with the continuous mode and second pattern which is programmable, as during the night the temperature set on 30^{o}C, and during the working day it is on 24 ^{o}C, same for the heating pattern which set for 15^{o}C and 21 ^{o}C during the working hours. Figure 2.5 b illustrates the third pattern in the office area, as the temperature is changeable during the day because of the number of people inside the space. Figure 2.5 c shows the third pattern but in the meeting area. The third pattern maintains the cooling system even if there is one worker in the office room, as the thermal comfort was considered in this pattern parameters. After conducted these simulations in the Energy Plus program, the researcher found that programmable thermostat in the second and third pattern can save 22-50% in electricity and 47-87% in natural gas.

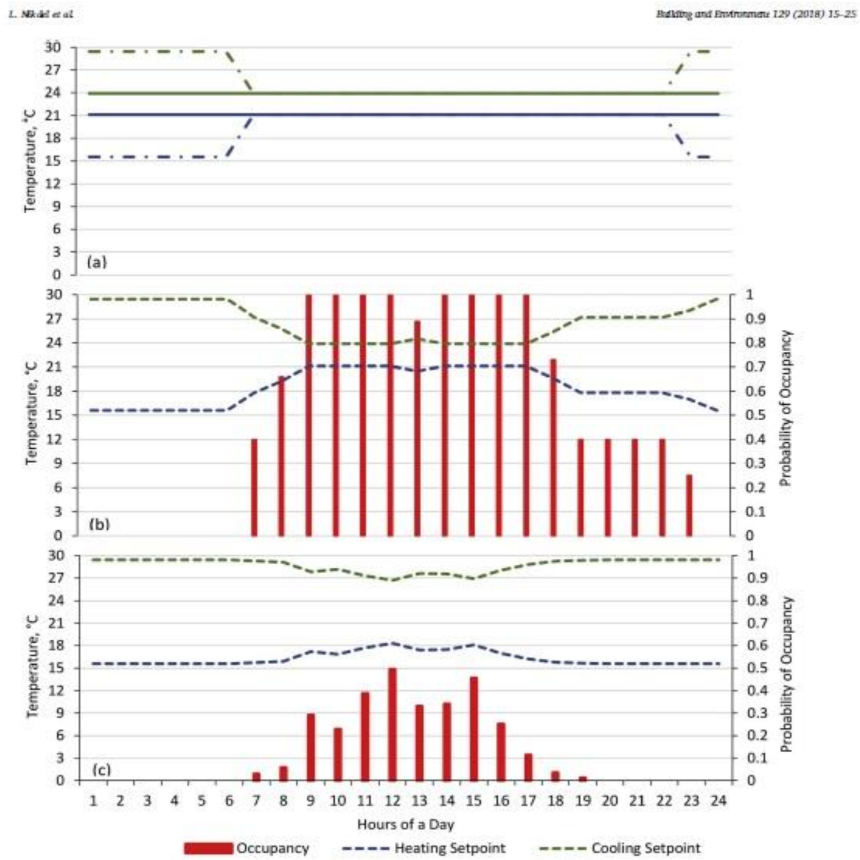

Figure 2.5. The thermostat patterns in the office building. (Nikdel et al. 2018).

2.5 Ventilation Strategies.

A large and growing body of literature related to types/strategies of the building ventilation were published. Most of the previous research papers discussed the ventilation strategies and the technologies that were used to monitor the indoor airflow. Several studies might suggest providing natural/mechanical ventilation mode. Below are some researches discussed plans and techniques for building ventilation design under three sections:

2.5.1 Natural Ventilation.

Natural ventilation methods generally depend on the opening side in the building sections and outside air direction and pressure according to the building orientation. Cross ventilation benefit from the window placement in the room, which cause different air pressure areas (high/low pressure). This method assists the air to withdraw within the room. One side window might not promote a pressure differential which leads to a low level of indoor ventilation. Another method of natural ventilation is the stack effect; it depends on the air temperature between the inside and outside the building. If the inside building has two windows at various level and temperature more than the outside temperature, the building ventilation is under stack effect. This diverse in air temperature cause diverse in pressure which allows air to move inside the building from one window and exhaust outside from the other one. Figure 2.6 shows the stack method relating to the air temperature. (Lechner 2015, pp. 295, 296 & 297).

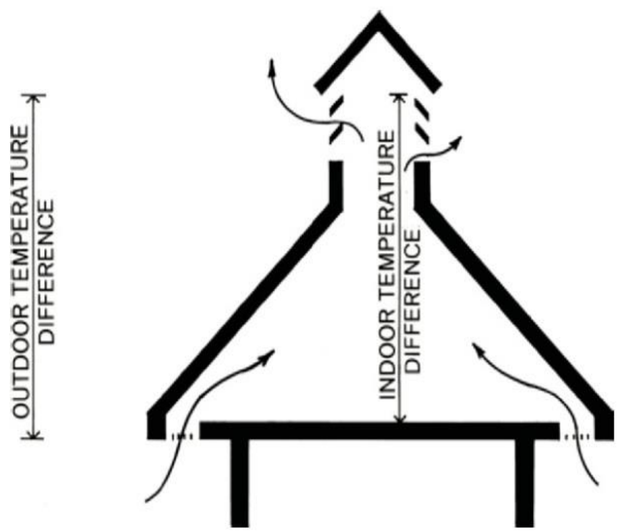

Figure 2.6. The difference in air temperature between inside and outside. (Lechner 2015, P 269).

One study by (Taleb 2015) examined natural ventilation mechanism in a villa in Dubai to reduce cooling loads around the year. The researcher found that the benefit of natural ventilation can be controlled by air direction and room opening sides. The design of one side window can not let the air to pass across the room, which minimises the opportunity to get rid of the warm air outside the spaces.

However, Warm climate with a high level of humidity in the UAE during summer months suggested using the cooling system to achieve indoor comfort level. Accordingly, natural ventilation might be proposed in the winter season only. As natural ventilation assists in reducing indoor air temperature and reducing the building mass temperature, at night, thermal mass can play an important role to conserve the cooling from the night to utilise it during the day.

Cross ventilation was also supported by Omrani et al. (2017), who discussed the procedure of natural ventilation. The researcher tested the one side opening and the two side opening for a flat in level five of G+ 36 building in Australia. The site measurement was used on indoor air temperature, speed and relative humidity in the warmest month, which is January. The researchers gathered the required information from the nearest weather station. They found the indoor air velocity in two side opening was more than the one side opening; they referred it to the pressure difference in the two sides opening ventilation which can enhance the indoor temperature.

However, in the UAE, natural ventilation has a specific technique, which is a wind tower. It catches the outdoor air to assist in reducing the indoor air temperature. As the wind tower works under the stack effect, the warm air from the internal gain elevates and escapes from the wind tower. In the winter months, it works to let the cold air enter the spaces. (Al-Sallal, Al-Rais & Dalmouk 2013). The researcher used this technique besides other passive strategies to design a villa in Abu Dhabi. The design steps were according to the Estidama, which is Abu Dhabi green building standards. With wind tower and other strategies, the design succeeded to decrease 59% of electricity usage.

According to Friess & Rakhshan (2017), wind tower in UAE considers one of the strategies in passive cooling to minimise energy consumption. But it is mostly used in villas. However, there are some obstructions to include the wind tower in villas design. For example, the outside air conditions/ standards that may carry dust, and extra cost for structured and designed the wind tower which needs to be in level more than the roof level to avoid any obstacles around it that effect its main function.

2.5.2 Mechanical Ventilation Strategies (CO_2 Controller).

Many suggestions were offered in mechanical ventilation like air distribution in the spaces and level of IAQ. One study by Cheng et al. (2019) discussed the horizontal air distribution method within the breathing zone in the office room with two employees. The grill of the fresh air placed on the one wall and, the returned grill set within the ceiling level. This type is known as stratum ventilation. The study focused on the amount of the outside air within this system and energy saving. The researchers carried out an experimental and numerical methods in the office room. They found that this type can save energy by 6.4% by considering the level of IAQ.

While a study by Shan et al. (2016), explained the type of fresh air distribution from the false ceiling which is Mixing ventilation (MV) with the passive displacement ventilation. They found that both system have their disadvantages relating to the employees' comfort level. As the main cause is the air distribution in the room. In MV, the cold air concentrates on the head and in the passive displacement ventilation, the air directed down from the head, which causes discomfort.

However, most of the studies relating to the mechanical ventilation focus on strategies of the indoor CO_2 controller. One study by Guyot, Sherman & Walker (2018) illustrated CO_2 Controller or demand control ventilation (DCV) method, which uses the signal to regulate the indoor airflow for the spaces when CO_2 or humidity becomes more than the setpoint. Several previous studies explained the DCV and its method. It modifies the amount of fresh air as per the level of indoor CO_2. The main source for the CO_2 is the people, as when indoor spaces are empty the airflow decrease or stop. There are different kinds of DCV relating to the building function/design, monitor working logic, airflow amount and distribution. However, Guyot, Sherman & Walker (2018) classify the DCV as per the airflow movement, and it can be listed as follow:

- Balanced- only DCV: which may work by the main system that provides air for many spaces or by separate controllers for each space. The amount of the airflow may regulate by using damper or by a fan for each area.This type of system capable of equalising between the supplied air and the amount of exhausted air.

- Exhaust- only DCV system: which also can operate by the main or separate system. However, this type of controllers works on maintaining the amount of exhausted air in the areas instead of airflow to the spaces. In other words, this controller can size the level of the CO_2 and works to get rid of it by controlling the exhaust system.

Overall, Guyot, Sherman & Walker (2018) classify the DCV as one of the intelligent systems to minimise the energy using and maintain the IAQ. While Ahmed, Kurnitski & Sormunen (2015) confirmed the benefit of the DCV on spaces that have a different number of people during the day. For example, open office, meeting spaces and atrium. Also, they measured the energy consumption and the IAQ for the office building in Finland. The building is under DCV, chilled beam (instead of FCU) and AHU. However, the system is linked with the district heating and cooling, which provide preheating/cooling and hot water. The researcher in that study used field measurement and simulation to define energy consumption with this system. The formula used in the DCV in the workstations office was the CO2 level should not exceed 700 ppm.

Figure 2.7 shows the difference between constant airflow CAV system and DCV in the workstation office. Diagram (a) shows the air temperature in both modes. Diagram (b) shows the amount of airflow in two modes which CAV keep supplying 600 l/s while DCV depends on CO_2 level to supply air as per required, as 600 l/s can maintain CO_2 less than 500 ppm. Diagram (c) illustrates the concentration of CO_2 in both systems as in DCV the amount of airflow keeps the CO_2 within 700ppm and should not exceed. Overall the researcher found that CAV consumes more energy than DCV and, can maintain the level of the CO_2.

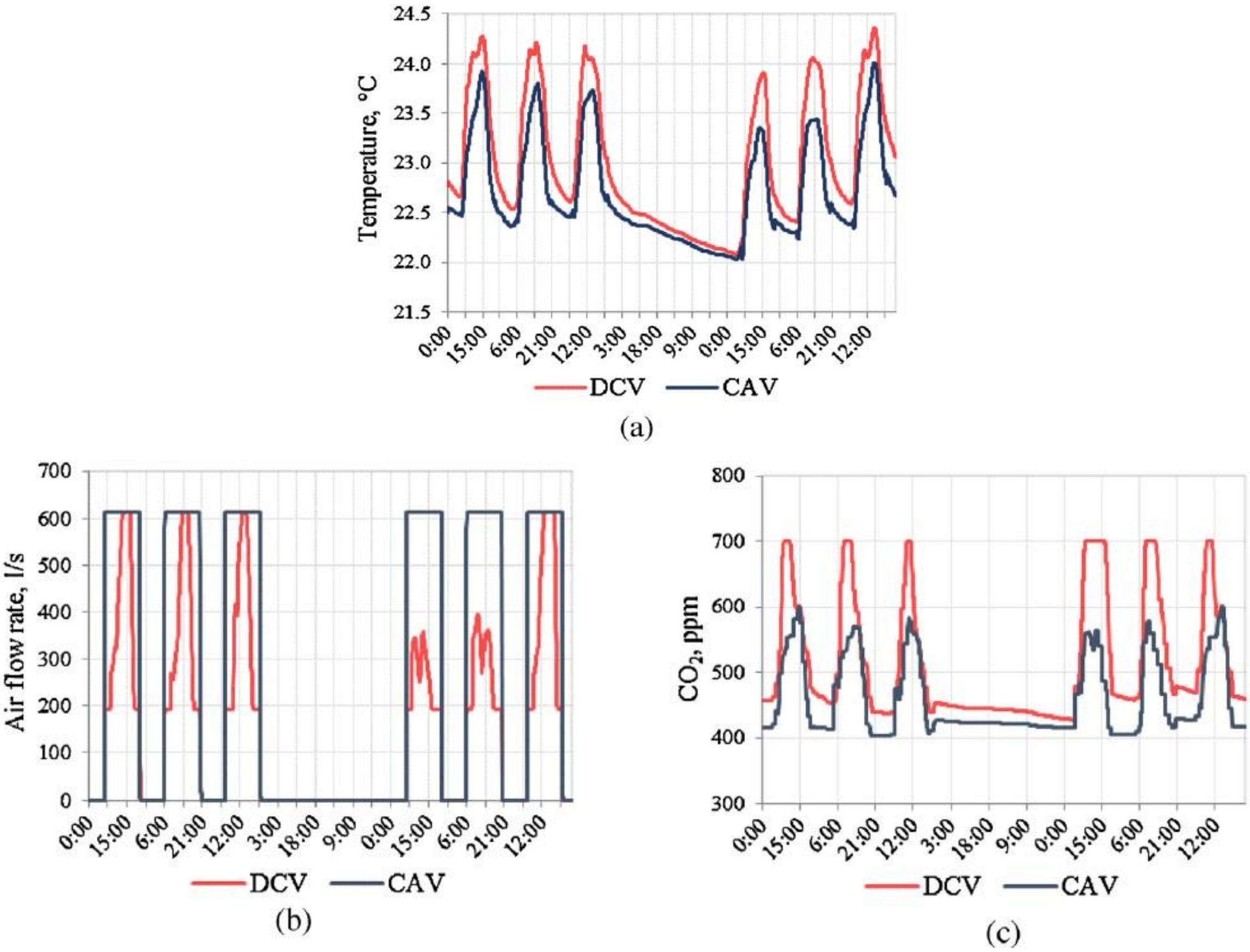

Figure 2.7. The difference between DCV and CAV in the office area. (Ahmed, Kurnitski & Sormunen 2015).

While Chenari et al. (2017) determined different formulas for the DCV to maintain IAQ inside the office building and find which one is capable of being used.The main estimation for the optimal DCV schedule for the office building was energy-saving. The office ventilation plans were:

- The airflow system worked on CAV as per the office working time despite how many employees were in the space. (CS1)

- The airflow system in this plan depended on the number of employees inside the space. Accordingly, in this plan, a variable air volume (VAV) utilised to control the airflow. (CS2).
- The third schedule planned on the formula that the level of the CO_2 should not exceed 1000 ppm. The CAV system works when the CO_2 level is higher than 1000 ppm. (CS3).
- The final schedule was similar to the third one but by setting a higher/lower level for the CO_2 control formula inside the space. As the CO_2 level should not be more than 1000 ppm and not be less than 500 ppm. So the CAV operates accordingly to maintain the CO2 level inside the space between 1000-500 ppm. (CS4).

Besides, the number of employees and the office working time were identified and used for all plans to conduct a simulation in Energy Plus software. The researchers found that the third schedule is the optimal one by using less energy and maintaining satisfied CO_2 level. As the first schedule consumes more energy than the other schedules, and final schedule uses more energy than the third one because of its control formula. Figure 2.8 shows the four patterns and fan energy, as CS3, which is pattern three used less energy compared with other patterns.

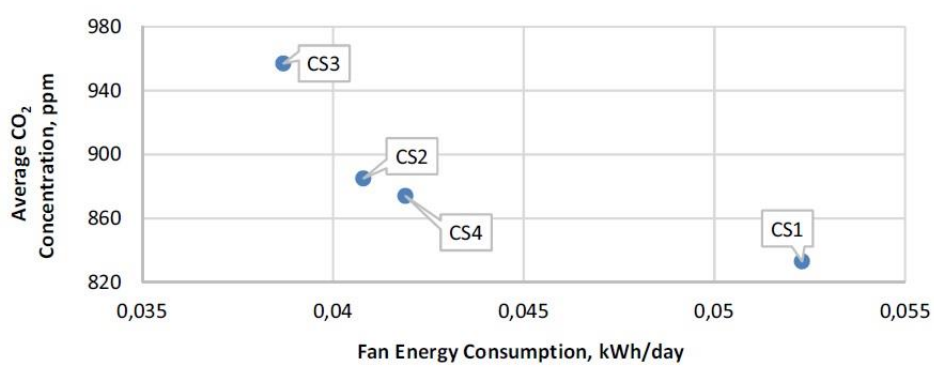

Figure 2.8. The four patterns and energy consumption. (Chenari et al. 2017).

2.5.3 Mixed- Mode Ventilation.

Much of the current literature of the HVAC system pays particular attention to the energy consumption of the system. However, several studies also focus on ventilation types and indoor environmental level, how to achieve and balance with the HVAC system energy-saving strategies. One type of ventilation mode is hybrid, or mix mode ventilation which open window to provide natural ventilation and mechanical ventilation might use to achieve thermal comfort and level of indoor air quality when natural ventilation can not.

The space system mode transfers from natural to mechanical ventilation by the occupants or specific software algorithm; this process assists in decreasing the overall energy using for the building. The previous studies examined this mode recorded optimistic outcomes for office spaces. Hybrid ventilation differs in design than the other types of ventilation like only natural ventilated building and mechanical ventilation. Most of the buildings were applied natural ventilation only, showed negative outcomes regarding the thermal comfort of the occupants particularly for very hot/ cold areas, for this purpose the mix mode was estimated in the building system and was quite used lately. In the mixed-mode ventilation, the natural system provided with the monitor to regulate the open window time integrated with the mechanical ventilation system like AHU. The centre for the built environment at the University of California (2013 in Salcido, Raheem & Issa 2016), issued details about the types of hybrid ventilation by grouping them under different considerations like which/when space can use natural or mechanical ventilation during the day or months. The hybrid ventilation might be listed as:

1. Concurrent: which mechanical and natural ventilation work on the same hours during the day in one area. When the natural can not meet the needs of the people's thermal comfort or the quality of the indoor air. Mechanical ventilation considered as a further option besides the natural one.

2. Changeover: which mechanical and natural ventilation applied for one indoor area but in various hours per day or various months per year. However, this type needs to design/manage the profile of the system time with a specific algorithm which switches between the mechanical and natural ventilation as per the internal loads and outside dry bulb temperature. Or the design may give a sign to the people inside to open/close the window or the thermostat.

3. Zoned: which mechanical and natural ventilation run in many indoor spaces of the building in one time. Figure 2.9 illustrates the three types of mixed-mode ventilation or hybrid system.

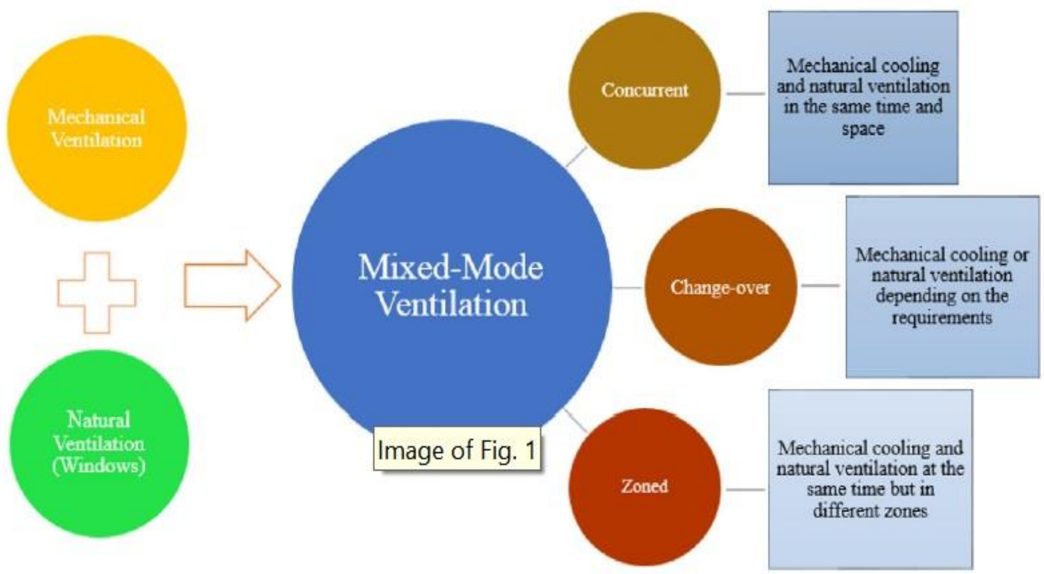

Figure 2.9. The types of hybrid ventilation. (Salcido, Raheem & Issa 2016).

As mentioned above this type required specific controllers and management, and many studies demonstrated that it is challenging to depend on the occupants to manage between the natural and mechanical ventilation.

Zhang et al. (2018), obtained a notable reduction in energy usage when suggested and discussed examples of the how-to monitor the IAQ and thermal level in an office building in the humid and warm climate. The study concentrated on the adjustment of the indoor humidity between the natural ventilation and dehumidification system. The researchers promoted a type of algorithm to determine when the dehumidification works. This monitor supported the energy-saving plus maintains the IAQ for the office building. The monitor design working under three factors or standards, which are: Level of airflow depends on in/outside dry bulb temperature and level of CO_2 condensation and; the degree of thermal satisfaction and humidity. It is responsible for window and humidification system profile. All the variables were set up, for example, the inside CO_2 level should not exceed 1000 ppm, as the window open to provide outside fresh air. Also, the dehumidification system works and the window lock, when the temperature of the internal walls and furniture is less than the outside dew point in one degree. This process was implemented by using the actuator. It works with the monitor algorithm to lock/unlock the window and the dehumidification system.

However, (Rasheed & Byrd 2018) investigated the differential between the completely natural ventilated building and mix mode system in another building by surveying the employees' comfort level in Newzeland. The survey conducted under some criteria Like air temperature, light, level of the noise and the employees' wellbeing. The researchers found that the employees in the natural ventilated building which is (A) were not completely feeling comfortable relating to the air temperature in winter compared with mix mode building (B) which also the occupants recorded their discomfort about the air temperature for all seasons. These could be relating to the building management system. Also, the employees in building A had problem with outdoor noise compared with building B, which the noise problem was from indoor. Overall the thermal comfort level in the natural ventilated building was better than the mix mode system. However, the researcher in this study demonstrated that the survey conducted only in two building and in the cold season, which may impact the outcoming. On the other hand, the previous research in New Zealand found that employees and the engineers choose to use the HVAC system and mix mode more than the building designed with natural ventilation only.

Overall, these studies highlighted the importance of using mixed-mode ventilation which is proper in most of the climate, but it needs to be managed and controlled to achieve the acceptable level of energy- saving in the HVAC system and secure the thermal comfort and IAQ.

2.6 Consideration Should be Taken in The HVAC System Strategies.

2.6.1 Thermal Comfort.

Most of the research papers that discussed thermal comfort are focusing on the factors that have a direct impact on the occupant wellbeing. Building energy-saving strategies might affect occupant thermal level. For example, increase the thermostat setpoint to save more energy without considering the occupants' comfort level. The factors that several studies determined are divided into two tracks: factors related to the occupant themselves like whether they are female/male; young/old. The second track associated with the indoor environmental quality like the temperature, amount of the airflow and relative humidity RH. Most of the studies referring to the ASHRAE standard 55, which is responsible for analysing indoor occupant thermal comfort.

Silva, Ghisi & Lamberts (2016) conducted an experiment in the office building to find an optimal condition or indicator to assess the employees' thermal comfort. They used methods like a predicted mean vote (PMV) to understand the impact of different factors on the employees. They used the Energy Plus program to find out the thermal comfort factors hourly. However, they found it is not simple to find a fixed indicator for thermal comfort to use it in buildings, as it depends on many elements to be rated. Table 2.1 shows the elements that were used in (Silva, Ghisi & Lamberts 2016); these elements have a direct effect on the indoor thermal comfort level, which are a range of metabolic, type of the clothing, the amount of airflow and its temperature.

Table 2.1. The input variables used in the simulation. (Silva, Ghisi & Lamberts 2016).

Independent variables for simulation experiment.

Independent variable	Unit	Distribution
Clothing level (warm period)	clo	U (0.57; 0.85)
Clothing level (cold period)	clo	U (0.85; 1.14)
Metabolic rate	W/person	T (99; 126; 180)
Air velocity (warm period)	m/s	T (0.05; 0.20; 0.80)
Air velocity (cold period)	m/s	T (0.01; 0.10; 0.20)
Set point temperature (warm period)	°C	D (23; 24; 25; 26)|(0.15; 0.35; 0.15; 0.35)
Set point temperature (cold period)	°C	D (19; 20; 21; 22)|(0.15; 0.35; 0.15; 0.35)

Note: U means uniform distribution (lower value; upper value); T means triangular distribution (lower value, mode, upper value); D means discrete distribution (levels)|(probabilities).

However, ASHRAE standard 55 introduced thermal comfort has many factors that affect the fulfilment of the human being inside spaces. The body can lose sensible and latent heat by many processes like conduction, convection and radiation. However, these processes are subjected to many factors, as mentioned earlier in this section, like environmental and human factors. (Ashrae handbook 2017).

As per Rupp et al. (2018), the thermal comfort research papers conducted either in test rooms or onsite measurement. The authors found that the test room studies are more helpful in gathering and understand data than onsite studies which mostly depend on employees opinions. However, they conducted a survey in many buildings in Brasil for two years. The study concentrated on the employees' physical properties. Some buildings are under hybrid ventilation system others use the HVAC system only. This study focused on the employees' thermal comfort reporting without changing the indoor conditions. In other words, just to examine the comfort level in a real environment. They found that females are more sensitive than males regarding the level of cooling; they prefer a warm indoor environment. Also, obese people prefer to operate the cooling system most of the time.

While Aryal & Becerik-Gerber (2018) reported the employees' opinion of which thermostat setpoint fulfilment their wellbeing to investigated the thermal comfort combined with the indoor air temperature setpoint (energy-saving) for the office buildings in a different location around the US.The employees reported their opinion according to the ASHRAE zones, which is from +3 to -3. The -1 to +1 is for neutral level, -3 and -2 is for overcooling and +3 and +2 for warm spaces. The researchers utilised and grouped the outlines of the comfort levels by using the results from the employees' suggestion and opinions. These outlines assisted the researchers in carrying out a computer simulation to find the energy-saving by considering various setpoints. Figure 2.10 shows the three levels that affect the comfort level, and that used in the previous study.

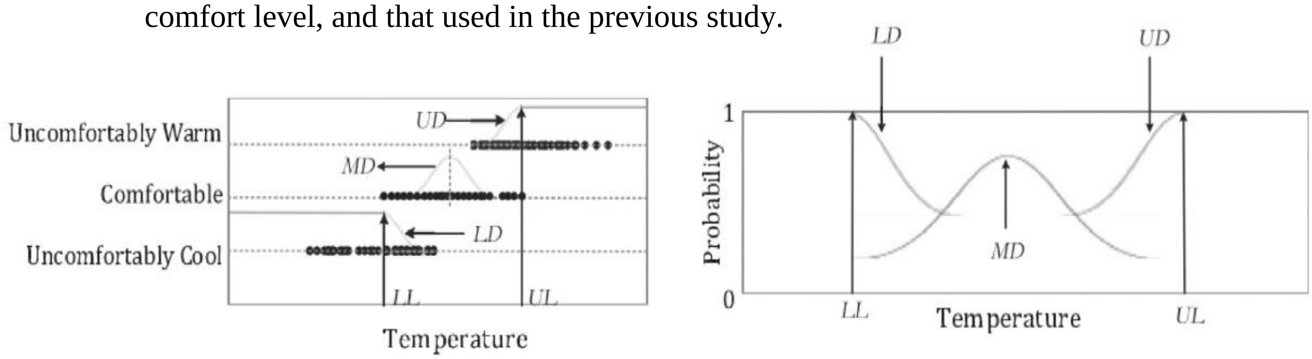

Figure 2.10. The comfort levels that were considered in the study and in the previous research. (Aryal & Becerik-Gerber 2018).

The studies carried out in the winter and summer season to assist the researchers in finding the optimal setpoint for the two seasons. The results from occupants opinions for different types of building were compared with a usual setpoint for the thermostat which is 22.5/24; They found a high level of thermal comfort for the employees with their gratitude at the same time they achieve energy-saving which can reach to 7.3%.

The study by Aryal & Becerik-Gerber (2018). suggested the idea that each building has its properties in achieving thermal comfort relating to its function and occupants satisfaction. So it is difficult to find a fixed indicator for thermal comfort which support the idea of (Silva, Ghisi & Lamberts 2016)

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2.6.2 Occupants Health and Indoor Air Quality (IAQ).

The ventilation types, strategies and air distribution are essential to minimise the indoor pollutants. The level of CO_2, volatile organic compounds (VOCs), particulate matter are the most common indoor pollutants. The amount of air exchange inside spaces (airflow/exhaust) is vital to maintain the CO_2 level. Increase the amount the contaminants can affect the occupants' health and productivity at that point; the building is described as sick building symptoms (SBS). Many relating studies conducted in the office spaces that might be due to the fluctuating in employees number.

As per Shan et al. (2016), many studies introduced SBS. Generally, headaches, irritation, dry eye and problem in breathing for employees have been diagnosed as signs of low indoor air quality. As mentioned in mechanical ventilation strategies section, Shan et al. (2016) studied and carried out an experiment for two classrooms spaces in a university in Singapore with two types of ventilation (the mix- mode ventilation and passive displacement ventilation) to measure the level of the CO2 and the level of comfort between the employees and students. They found a high level of CO_2 in mix mode ventilation type that was because of the less supply/return in air velocity in m/s inside the space. They carried out many scenarios to enhance the level of ventilation as they involved the employees and the students with the questionnaire by reporting their SBS. One scenario was to boost the capability of the supply and return fan in FCU by set up another fan in the duct to raise the outdoor air velocity in m/s. to minimise the CO2 level. However; they found that the employees and students had suffered from health issues like headaches, difficulties in breathing because of the high level of CO_2.

While Wolkoff (2018) examined the effect of indoor humidity level on employees' health through reviewing relevant previous researches in office buildings. Most of the surveys claimed that the level of humidity (5% to 30%) has a significant impact on the occupants`eye irritation. In the other hand, studies also showed that raise in relative humidity(RH) could cause suffocating air to breath, even it affects the VOCs level negatively. As per Wolkoff (2018) the most agreeable air quality is minimal RH and air temperature after reviewing the research papers which used survey methods.

The study also focused on RH and the influenza virus. As many studies tested the level of RH Absolute Humidity AH and the time the virus can last/ pass from person to another in indoor spaces and their sustainability. Some studies agreed that some viruses could sustain in the high level of humidity other viruses could sustain in a low level of humidity. However, previous studies supported the idea that the type of virus also has a significant impact on its sustain/ transfer in the airstream. Lowen et al. (2007 in Wolkoff 2018), found that some viruses in the low level of RH the breathe out can vaporise more quickly in the airstream and stay more time, as air molecules in high RH can absorb the droplet from the breath, which raise its volume and its precipitation.

Wargocki & Wyon (2017), highlighted important questions, in which way and level dose the IAQ affect the people productivity. The researcher replied to the questions by reviewing previous studies. One specific highlight is the connection between IAQ and employees' productivity in office buildings. Most of the studies agree that VOCs and CO_2 have a significant effect on employees level of working. Researches found that CO_2 concentration at 3000 ppm may affect the ability to read in some cases. At the same time, most of the studies support the idea of increase the airflow rate by 20-30 L/s per person. Figure 2.11 shows the per cent of airflow to employees working level.

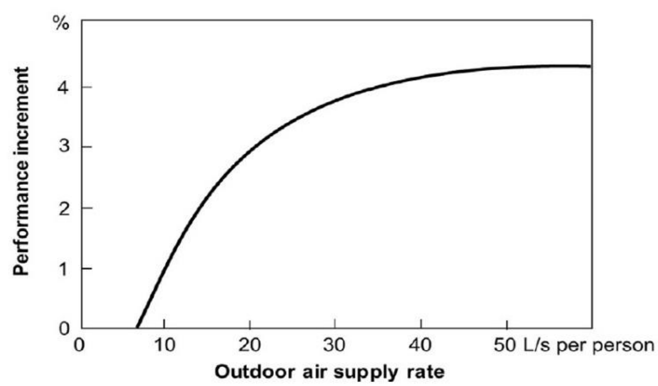


Figure 2.11. airflow rate L/s per person with the working level. (Seppanen et al. 2006 in Wargocki & Wyon 2017).

One study by Park & Yoon (2011) carried out an experiment for three weeks on a test room which was newly coated the wall and floor, so the levels of the indoor emissions were increased. The experiment was to change the airflow rate in L/s per person under the same situation. They involved students with doing some typing task in the experiment to identify the level of their work under different flow rate. Besides, they conducted some measurements for the emissions under the same flow rate. Table 2.2 shows the level of these emissions with the 5, 10 and 20 L/s per person of airflow for 8 hours. Relating to student productivity, the researchers found a significant increase from 2.5-5% in many types of office tasks with airflow 5 to 20 L/s per person which cause a decrease in the level of indoor emissions.

Table 2.2. The concentration of pollutants in the office room with different airflow rate. (Park & Yoon 2011).

	Designed ventilation rate		
Environmental parameters	5 l/s per person	10 l/s per person	20 l/s per person
Air temperature (°C)	23.6 ± 1.1	23.4 ± 1.0	23.5 ± 0.9
Relative humidity (%)	46.2 ± 5.2	48.1 ± 4.5	46.7 ± 4.2
Air velocity (m/s)	<0.1	<0.1	<0.1
Illuminance (lux)	462 ± 1.9	493 ± 2.6	485 ± 2.1
Sound level[a] (dB)	52.1 ± 0.4	53.1 ± 0.5	54.1 ± 0.3
Outdoor air supply rate[a] (l/s per person)	4.9	10.2	19.8
PM10 ($\mu g/m^3$)	23.8 ± 4.4	13.8 ± 1.8	8.3 ± 1.0
CO_2[b] (ppm)	1364.4	872.2	636.1
Formaldehyde[a] ($\mu g/m^3$)	55.6	43.6	30.5
Total volatile organic compound[a] ($\mu g/m^3$)[a]	2376.1	1571.7	1163.3

[a]Average value of three times sampled (8 h sampling time at each exposure).
[b]Average concentration at steady-state.

The pollutants source might differ from one to another. For example, The CO_2 may increase due to the internal gains like the number of occupants.VOCs releases from indoor finishing materials (paints, adhesives, wood finishing lacquer). VOCs include carbon, aldehyde, alcohols.VOCs can cause eye/ nose allergies, asthma, nausea and eventually can cause serious health issues as VOCs consider carcinogenic materials. However, particulate matter (PM) may come from outdoor pollutions and enter the human lung, which may cause a health problem. $PM_{2.5}$ which mean mass size of 2.5μm.

It can easily enter the human lung. To prevent $PM_{2.5}$ access the indoor spaces, many types of filters have been examined like medium and high-efficiency filters (MERV/HEPA). (ASHRAE handbook 2017).

One study by Liu et al. (2017) reviewed the material types that air filters made of along the history, which are: glass fibre, carbon fibre like polypropylene that is more efficient because of its spongy structure properties which increase its capacity to intake the particular matter. Nanometer fibre assists in giving a considerable size to the filter, which also increases its capability to capture the PM. Generally, Fibreglass considered the most usable material in the HVAC system. Figure 2.12 shows the typical filter, which is a panel filter.

Figure 2.12. panel filter which uses in the HVAC system. (The engineering mindset 2019).

Chapter 3 Methodology

3.1 Introduction.

Generally, understanding the nature of research is essential to specify the type of methods. Qualitative and quantitative are a common expression for research types. Quantitative analysis may build on control, prove or solve the problem upon numerical results opposite to qualitative research which relies on the explanation of the behaviour for some people or about some matter. (Groat&Wang, 2013, P.69). Besides, the applicable method depends on research time, cost and availability of the chosen method. These factors affect the accuracy of the results.

This chapter investigates the different methods that were used in previous studies. The focus is on specific papers that covered building energy and indoor air quality relating to the HVAC system. Also, it discusses the advantages and disadvantages of each method which assist in identifying the technique in this research. At the end of this chapter, the method is clarified for this research that supports the study core.

3.2 The Parameter of this Study.

To chose the proper method, the variables should be identified. The primary purpose of this study is to examine some strategies for the HVAC system in the office building to improve energy consumption for sensible and latent loads. Also, study the indoor air quilty regarding the CO_2 level for the office zones and thermal comfort for the occupants. As mentioned earlier in the introduction chapter in study motivation section, this type of strategy calls active modifications or active design. Overall, this research study energy saving in two-line, one through indoor air temperature and, second indoor level of ventilation as the focus is about controllers' formula for mechanical and natural ventilation. Below is a brief explanation of active strategies:

- Use different thermostat setpoint for cooling loads in the summer season.
- Study the internal gain for each office zones.
- Apply different schedule for the thermostat in the cooling system.
- Design the CO_2 control formula for the office zones.

- Apply different profile for the outside air supply system. For example, the one that depends on the thermostat schedules, or that works under CO_2 formula.
- Apply natural ventilation for winter scenario combined with the mechanical system and focus on the window controllers, which is under the specific formula (temperature and relative humidity). Figure 3.1 illustrates the overall research parameters.

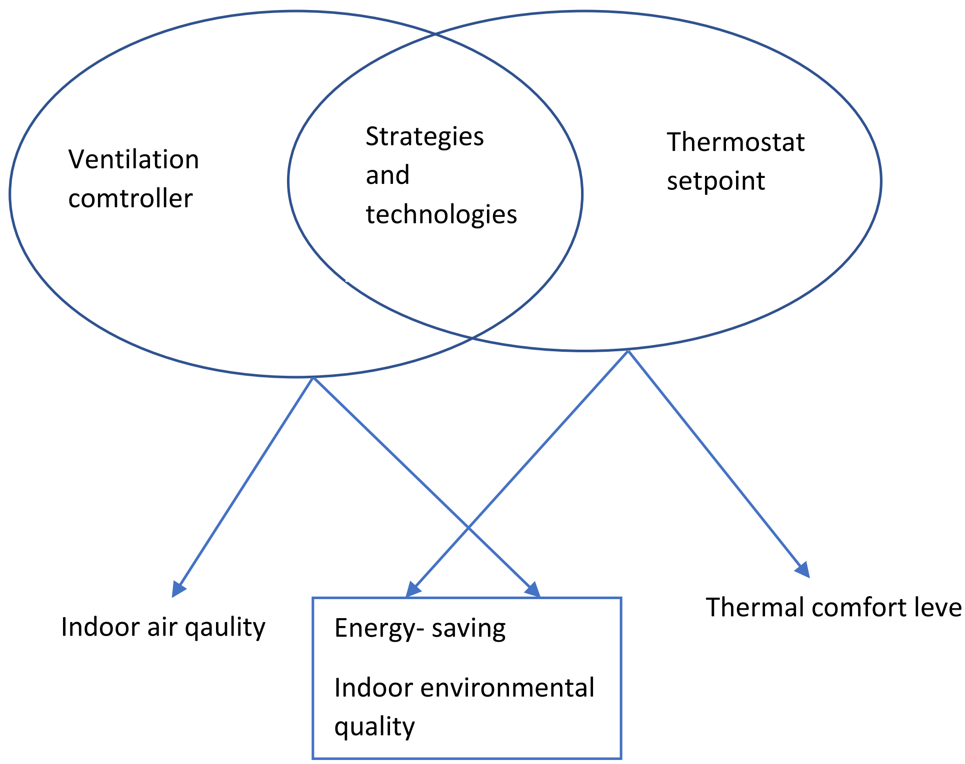


Figure 3.1. The research parameters and consideration. (Author).

3.3 Different Methodologies for HVAC System.

3.3.1 Field Measurement.

This method conducts in a real environment of the building without any previous planning for the chosen zone. It involves the unpredictable behaviour of the occupants, which consider a positive point for this method. So far field measurement method has been applied mostly in studies relating to indoor air quality(IAQ).

Felid measurement method in some papers was supported by the second method like interview or survey to get more information about the tested zones.

A recent study by Li et al. (2018) examined the IAQ in the meeting room in one office in Hongkong. The office room designed without windows, which means that the ventilation depends totally on mechanical equipment. The HVAC system for the office is water chiller and fan coil unit. The CO_2 level was sized to evaluate the IAQ by using AWAIR instrument, which was placed in the office rooms. This instrument was already approved and confirmed as an efficient tool to size the CO_2 level. The data were registered and saved every 15 minutes in a software application. The field measurement continued for two Summer months to get more accurate data.

Similarly, Merema et al. (2018) conducted a case study investigation in many types of zones, like two office building in Belgium to study IAQ. The two buildings have the same HVAC system which is AHU with the CO_2 monitors. The field measurement continued for one year. The CO_2 levels were gathered from the existing CO_2 monitor and from newly installed monitors to ensure the accuracy of the results. Also, other information about the supply air level was collected from the building management system (BMS). The main point of the study was to evaluate the IAQ; however, energy-saving for the fan was considered in one office by using a simulation program.

A study from Merabtine et al. (2018) used field measurement methods not just to evaluate the CO_2 level but also for heating loads for school and office building in France. The measurement conducted for three years to understand the indoor environment. The building is under BMS, which the data were gathered from its system. Besides, some questions were given to the student and the employees to understand their thermal comfort level.

As mentioned earlier, this method primarily can be used to measure IAQ. In the last two papers, the researcher used the second method to examine more parameters, especially when it involves measuring the HVAC operation efficiency.

However, the researchers need to take approval to conduct the field measurement as it is done within the working hours. Besides, this method may require more time to get an accurate result as per the papers above. The researcher in this method may ask to be aware of the placement of the measurement devices to avoid any error or uncertainty in readings. It is likely that, field measurement can be used to understand the performance of the HVAC system in the existing building to be developed and used in the new design building.

3.3.2 Experimental and Field Measurement Methods.

This methods used in some papers, for example, One study by Goyal, Barooah & Middelkoop (2015) conducted experimental research in a real environment in the University of Florida. The experiment was carried out in one office room in the university, which has two employees only. The room has the VAV box that means separate thermostat. The building is under the BMS system. Some information was collected from BMS. However, to be more accurate, a multi-monitors was set up to receive specific information about the office room. This experiment focused on monitor pattern for the air temperature and the amount of the airflow. The researchers developed a predictable occupant formula for the monitor to examine the operation efficiency in the office room. This study depended on experimental method supported by the measurement instruments with the BMS system to achieve the new monitor formula.

While (Jing et al. 2019) carried out an experiment in a built chamber. The study was about how to manage the level of ventilation in many zones to achieve energy saving in the HVAC system. A mock-up for small boxes arranged in the same row with ducts and dampers were built inside the chamber. DCV and pressure monitor were set up. In this study, the ventilation was studied and measured upon the static pressure and fan speed in the ducts, not on internal loads like occupants. Figure 3.2 illustrates the built champer that was used in the experiment with the four tested areas.

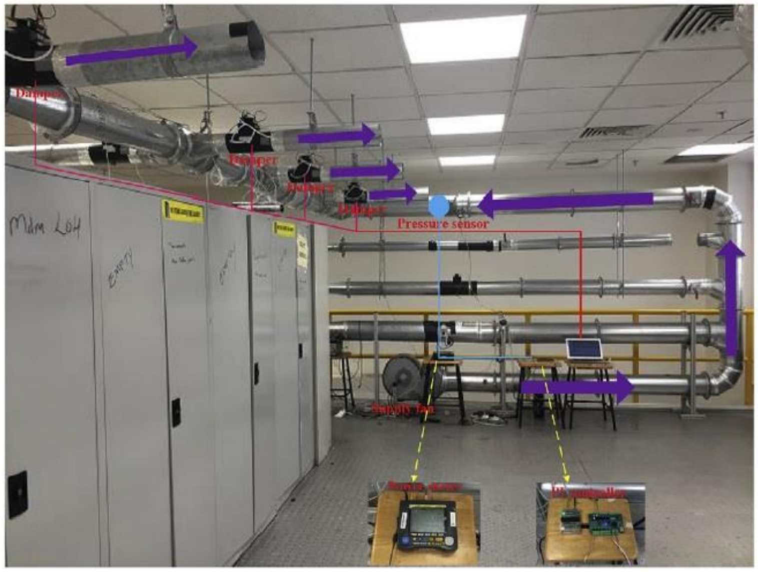


Figure 3.2 the test chamber. (Jing et al. 2019).

Anand et al. (2019) Examined some ventilation schedules using variable air volume VAV. The study was used field measurement and experimental methods in an educational building which contains different types of spaces like open office and classroom. The researchers used the building monitors to gathered information about the spaces. For example, thermostat, BTU metre for the HVAC system loads. However, some monitors were set up like a camera to identify the number of people inside the spaces. The measurements were carried out for 90 days. According to the gathered information which supported by numerical calculation, the researcher tested some ventilation schedules to improve the energy efficiency of building operational system.

This method, when it uses to examine the HVAC system, might be done in a lab or the existing building. However, It is hard to build a real environment in a lab with a full HVAC system like in research paper for (Jing et al. 2019) or find an empty unused space in an existing building to manage the test.

The researchers in this method aim to find a problem with its result or prove a specific situation. However, if it is done in a lab, the input variables may not agree with the dynamic life in the buildings. (Groat&Wang, 2013). Like the number of occupants and their behaviour. Besides, this method requires time, and it is costly to create an environment that corresponds to the real one. However, it could be conducted in an existing building, but it needs permission to prepare for the experiments. Like in papers Goyal, Barooah & Middelkoop (2015) and Anand et al. (2019) was conducted in a real environment which assisted the researcher in finding optimal scenarios for the ventilation system.

In general, it seems that the researchers support their experiments by field measurements to develop their tests. Also, it has commonly been assumed that the experimental method might be used to understand the HVAC operation or test some hypotheses before being applied in a new design. The experiments can be done many times if it is in a separate test room same as the study from (Jing et al. 2019) by using a chamber and examine many strategies.

3.3.3 Simulation Methods.

This method can conduct alone without any supporting one. However, it might need a field measurement or occupants interview to collect more data to be entered into the software platform. Supporting methods may assist an energy model simulation to be more close to the real environment, and the results more accurate.

A study carried out by Ben-David & Waring (2016) in office buildings in 14 location in the US to examine energy efficiency. The computer programme was used to conduct a simulation from one hour to full-year by using Energy Plus software. According to the researchers, Energy Plus is widely used relating to its power to run an energy model for the building. The main focus of this study was to manage the mechanical ventilation amount of the airflow and to use economiser regarding the outside weather. Also, examined natural ventilation strategies which can be used in specific days of the year. The windows were programmed to open/close according to the outside temperature. The flexibility of running a software motivated the researcher to test different policies and climates for one year to find accurate results for energy saving.

This study built a typical office building in the Energy Plus software, and the data was entered from ASHRAE standards. Figure 3.3 shows the 3 dimension (3D) and the internal loads for the office building that was examined in the simulation program.

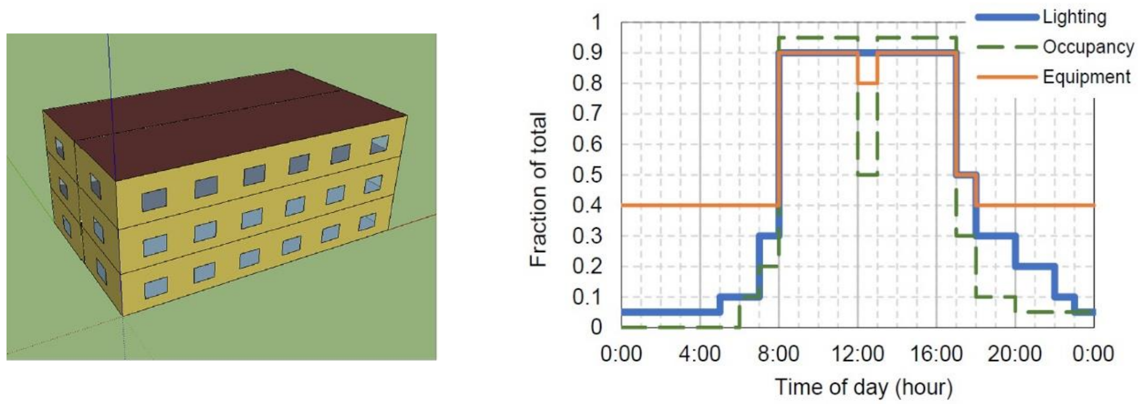


Figure 3.3 Typical office building and the internal load. (Ben-David & Waring 2016).

In the same vein, Rackes & Waring (2017) conducted a model simulation in Energy Plus software as it has confirmation from ASHRAE. The simulation was run in different types of office building related to their HVAC system. One of the offices has a Constant Air Volume (CAV), and the other has a Variable Air Volume (VAV). The simulation was done under using advanced devices and controllers to achieve energy saving, for example, DCV and Economizer. Rackes & Waring (2017) argued that using simulation methods gave the researcher a space to examine more input variables like passive and active one. For example, the insulation materials and glazing types. And for active procedures, reset the thermostats and their profile.

While a study by Weerasuriya et al. (2019) used simulation methods in the 40-floor residential building in Hong kong. The researcher used eQUEST to examine some strategies relating to mechanical and natural ventilation. The researchers claimed that eQUEST is one of the common software that has applied to evaluate building energy saving. The simulation was conducted from April to October. One strategy was using natural ventilation when the air temperature outside is less than the inside the windows open.

Also, used CONTAM software to conduct an air movement and pressure through the building and Ansys for CFD analysis. Overall, this study used three software to test and understand different strategies in one building.

While Fan & Ding (2019) conducted a simulation on a library building by using Energy Plus program. The main idea was to find a proper schedule for the cooling system by studying many changeable data and previous loads of the library building. The input data was collected differently. Some data was from Building Automation System (BAS), others calculated by using numerical equations. The supporting methods assisted the researchers in understanding and getting specific data for the library building, which led to testing more patterns that affect the cooling loads.

Overall, the simulation method might give a complete idea of the energy model, as most of the computer program conduct simulation for a full year with less time and cost. Most of the research papers which were used this method studied the effect of the HVAC system on energy saving of the building. The researcher can test many scenarios, materials new devices in a limited time and find a proper solution for the problems before being used in a real environment. (Groat&Wang 2013, P.349-351). However, the reliability of the results depends on the accuracy of the input data. To build an artificial environment in the computer program, the entered information or data should be analysed. Field measurements and interview with occupants may assist in collecting more correct data, as the researcher needs to provide specific data for each problem to get an accurate simulation. For example, Fan & Ding (2019) used information from the BAS of the library building to conduct a simulation in Energy Plus.

3.4 Selected Method.

Given all that has been mentioned so far, Most of the papers used field measurement methods to study and understand the indoor building environment or to understand problems for the HVAC system in the existing buildings. Experimental methods consume more time, and it is costly to build a test room with the full equipment of the HVAC system to create a problem and solution; however, both methods can be carried out in a real environment with the unpredictable behaviour of the occupants.

On the other hand, most of the HVAC studies asked for advanced software programs which have a variety of the HVAC design, monitors with their specification, drawing section and have the ability to conduct many scenarios. Computer programs for energy model divided into energy simulation programs, monitors planning programs and program that can perform both. However, all the software are essential to carry out quick and simple HVAC research, especially when they test monitors and their effect. As it is difficult when examining the HVAC parts with the monitors by using field experiments in the existing building. (Atam 2017). Walsh, Cóstola & Labaki (2019) agreed with other researchers that using computer software is one of the most skilful methods so far when creating many concepts for the energy model.

The applied method depends on the research question and problem. In this research, the main focus or question is on achieving energy efficiency of the HVAC operation strategies and technologies in the office building in Sharjah. In an area like energy efficiency for the HVAC system, which required many testing scenarios to identify cooling or heating loads per year, computer program simulation might be an appropriate method and one of the most practical approach to conduct different scenarios for the HVAC system. Besides, field measurement conducts in this research to collect and understand more information about the building. For example, the measurement of CO_2 level inside the offices' area.

3.5 Selected Simulation Tool.

According to the research papers, programs like Energy Plus and eQUEST were used to carry out an energy model. In this study, Integrated Environmental Solution IES VE was used as a simulation program. Americain Institutes of Architect through their Architect magazine(2015), classify IES VE as one of the five robust programs in building energy model. It is simple to use for Architects and Engineers also; it works in parallel with other drawing programs like Revit, Google Sketchup and Auto Cad DXF file.

IES VE gives a significant space to run energy simulation under many options from passive to active design. For example, building materials, schematic design, lighting, HVAC system, Building water service. The most important part in IES VE is working as per ASHRAE weather file which assists in giving an accurate result, ASHRAE 62.1 for IAQ, ASHRAE 90.1 for energy standards for building and ASHRAE 55 for thermal comfort.

3.6 Simulation in IES VE.

IES VE software was applied in this study to evaluate cooling system strategies for the office building in Sharjah. However, to reach an accuracy level in IES VE, many steps were managed. These steps can be listed as follows:

- ModelIT: This part assists in drawing 3D model, as IES VE assess the effect of solar radiation on the building according to the 3D shape.
- Aplocate: Through this application, the IES VE confirm the building location as per the ASHRAE weather file. The file gives complete information about the Dry Bulb Temperature and the level of Relative Humidity (RH) per year.
- Sun Cast: This part is essential to examine the solar radiation on the building sections like the roof, windows and opaque surfaces as per the building location.
- Construction Template: This part provides information about building materials specification and their thermal behaviour. For example, the glazing methods and the thermal transmittance (U value) in w/m^2k.
- Thermal Template: In this research, the thermal template is the most important part as it controls the type of HVAC system, cooling/ heating setpoint, operation profile, system control formula, air exchange method and internal gain. This part is better explained in the next chapter.
- MacroFlo: is responsible for introducing natural ventilation to the building. This dynamic can be done by optimising the volume flow in/out through the openable window as per wind direction. The MacroFlo template suggests the type of the window and the method of the opening.
- Vista pro: this application can examine and show the Apache calculation by choosing one or more of the variables related to the: room, HVAC system loads,

weather, building energy consumption and the carbon emissions. The results can be present as tables or charts per day, month or year. The researcher might conduct many simulations by changing the input data to get different results. This process assists to compare the results to find the optimal solution.

The simulation might be done in two way:

- either under the application that within the IES VE (default value);
- or by the information that the researcher entered as per the building specification. Figure 3.4 shows the IES VE main page, which represents all the applications that the researcher needs to carry out the energy model.

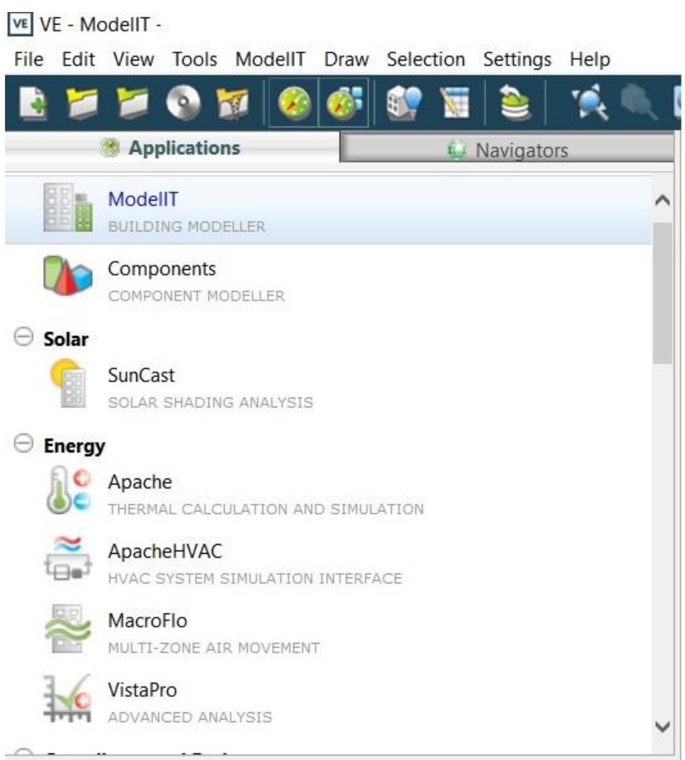


Figure 3.4. IES VE main page. (IES VE 2019).

Chapter 4 Simulation Model

4.1 Introduction.

This chapter describes and discusses the building simulation as per the chosen method. Also, it addresses the reason behind the selected building to evaluate active strategies. This chapter is divided into three sections:

The first section, Study and analyse of the general information of the building. For example, the location and direction of the building, the construction template, the Occupants behaviour, internal gains, and HVAC system also applied to the thermal template in the IESVE. Second, conduct a simulation for the base case and the proposed scenarios as per the information from the first section. Third, upgrade the scenarios by applying the CO_2 controller.

As mentioned earlier in the introduction chapter/ research keywords and motivation, the main reason for this research is to estimate the energy consumption for the cooling system in each scenario. The best one will be improved more by introducing a CO_2 controller to the spaces to get better indoor air quality (IAQ) and energy efficiency.

4.2 Input Data Collection.

This research evaluates some cooling strategies in an existing office building in Al Qasba canal in the Emirate of Sharjah in UAE. The information about the office building was collected by visiting the site many times. Also, meeting the employee who is in charge of the maintenance of the HVAC system in the building. The meetings assisted in getting the right information about the cooling system and its profile in the Summer Season, which is different from the Winter Season profile. Besides, communicated with other employees and asking them about their thermal comfort, the managing of thermostat setpoint and office timing. Also, got the building architectural and site drawings to use in the simulation program. Regarding the available information, summer and winter base cases were drawn and simulated in IES VE, then proposed scenarios under a different thermal profile.

To understand the building more, the researcher conducted some field measurements for indoor air temperature, relative humidity and, CO_2 level. The measurement tools (Extech CO240) were provided from the university. Extech CO240 measures air temperature, relative humidity, and CO_2 concentration. Regarding the CO_2 measurements, the range for this tool is from (0 to 9,999) part per million (ppm) and, its accuracy is (Reading ± (75 ppm + 5% of reading). The tests were carried out in the office building on 6^{th} of February. The results can be found in chapter 5 in section upgrading Summer and Winter Scenarios by applying the CO_2 controller.

The CO_2 measurements were conducted in the middle of the spaces, not under the air return or supply grill to minimise the error. This idea was clarified by Merema et al. (2018) .when the data was collected from two CO_2 sensors in the lecture room. The reading from the sensor near the return grill was very different than the other sensors inside the lecture room, so the readings near the return grill did not account in the research.

Some inputs data were taken from ASHRAE standards and Al- Sa'Fat. Also, the evaluation of the results is upon these building standards and regulation. Al -Sa'Fat is Dubai building strategies to achieve preferable out/indoor environment by decreasing the energy usage of all types of buildings and boost the level of indoor air quality. (Al Sa'fat, Dubai green building 2020).ASHRAE has standards for each aspect related to building design and human comfort and needs. For example, ASHRAE 90.1 is for energy consumption, especially for the HVAC system. ASHRAE 55 is for indoor occupants'thermal comfort, and ASHRAE 62.1 is for indoor air quality and ventilation. (ASHRAE 2020).

4.3 Case Study Office Building.

The office building in Sharjah was built in 2000. It has four blocks each block is in three-level (G+3 building). Different companies rent each block and level. The study was conducted in one block at the first level, which has $181.47m^2$ floor area. The building in (2D) is a rectangular shape, one of the long elevations faces the northwest direction which contains arc formed windows each window has around $5.8 m^2$ area as shown in Figure 4.1 from IES VE ModelIT section.

Figure 4.1 Simulation for the northwest of the office building. (IES VE, ModleIT)

The other long elevation faces the southeast direction with a rectangular-shaped window; each window has an area of 1.35 m^2. The southeast façade has a designed canopy which provides shading area, as shown in figure 4.2. As a result, the orientation of the building and the position of the canopy allow reducing solar exposure to the building, whether through opaque or glass exterior surface.

Figure 4.2 Simulation for the southeast of the office building. (IES VE, ModleIT)

Also, the office spaces located on the first floor, which is less affected by the heat transfer from the roof. One study by Li et al. (2015) evaluated the roof thermal performance as it is the major part of the building to exchange the heat from in and outside the building. This view was supported by Sirimanna & Attalage (2016) who examined the heat moving through the different types of roof to the inside.

The study was focused on the building with one or two levels in the hot, humid climate. They found that the roof temperature could be 10^{o}C more than the outside temperature.

Also, Suehrcke et al. (2008 in Sirimanna & Attalage 2016) found that around 20% to 95% from solar energy is store in the roof and gradually released to the interior spaces.

The Sun cast analysis in IESVE confirmed that the building elevations have less exposure to the Sun oppositely, the roof has significant exposure to the Sun, as shown in figure 4.3 and 4.4 which illustrate the two side of the building. These reasons assist in cooling down the interior spaces on the first floor, which have a positive impact on the cooling system.

Despite this benefit, in the base case, the setpoint for the air temperature in the thermostat is 21 ^{o}C working 24 hours in the summer season, which is energy waste. These result may be applicable to reconsider the base case strategy by applying different scenarios.

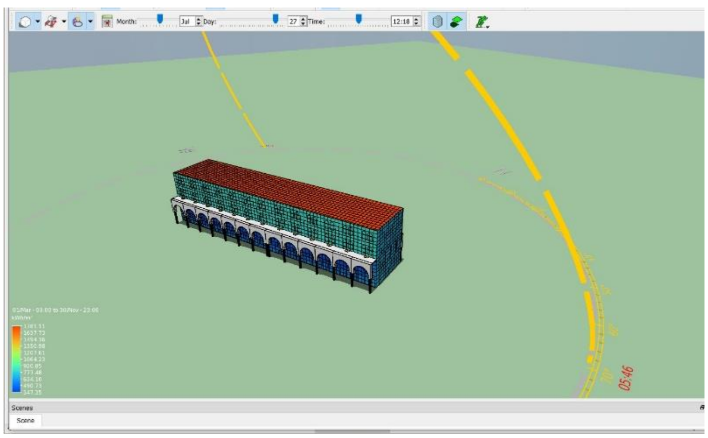


Figure 4.3 Sun exposure for the southeast office building. (IES VE, SunCast).

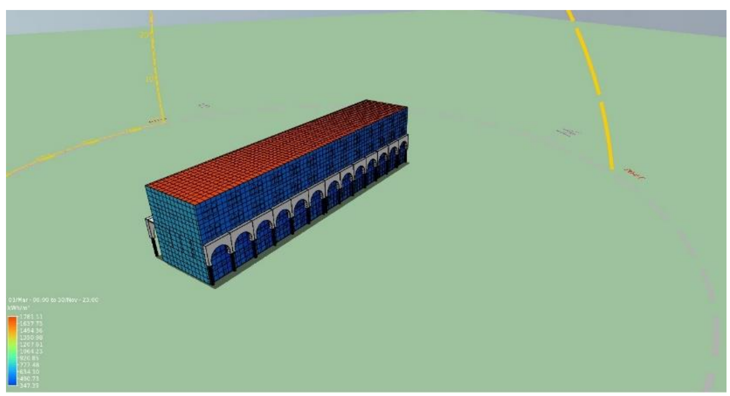


Figure 4.4 Sun exposure for the northwest office building. (IES VE, SunCast).

4.4 The HVAC System.

The main component for the HVAC system in the office building is Air-cooled chiller which is located in the roof. The system also supplies fresh air from the outside the building by Fresh Air Handling Unit (FAHU) which is working in a continuous mode. The researcher divides the office into three zones as per the thermostat that controls the Fan coil unit as shown in figure 4.5. Some internal partitions are ignored because each zone has one thermostat to monitor one fan coil. So these zones also help to make the IES VE simulation easier. As per the IES VE simulation, the name of the zones is zone A, zone 4 and zone 5.

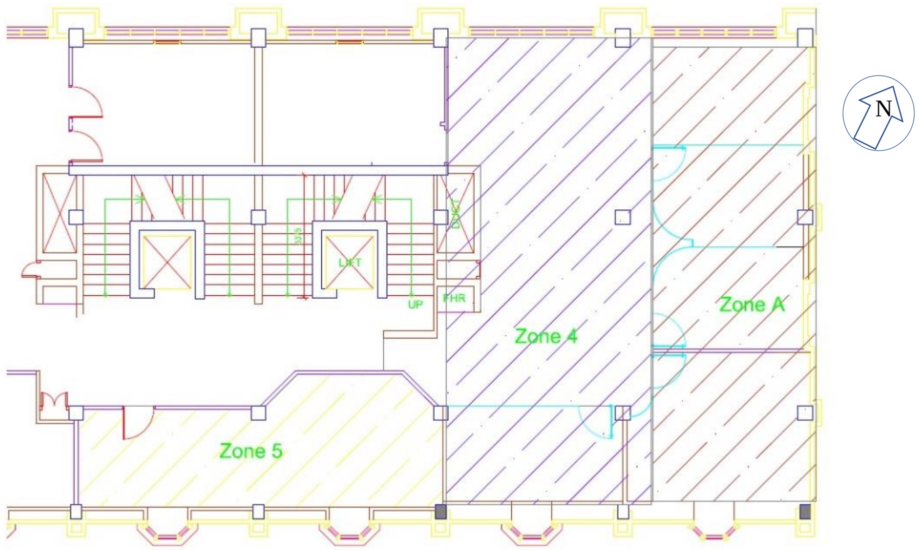


Figure 4.5 Office building plan, three chosen zones for simulation.

4.5 Sharjah Weather.

In Aplocate IES VE represents the weather file for all the station in the world from ASHRAE climate data. The case study in this research is in Sharjah UAE, so Sharjah location is applied to the Aplocate. The IES VE Aplocate shows the location latitude of 25.33 N and longitude of 55.52 E.

Also, figure 4.6 is shown the highest dry bulb temperature through the year, which is 46.10 ^{o}C in July. The highest Relative Humidity reaches to 100% in some days during the year, like 24th of September, as shown in figure 4.7.

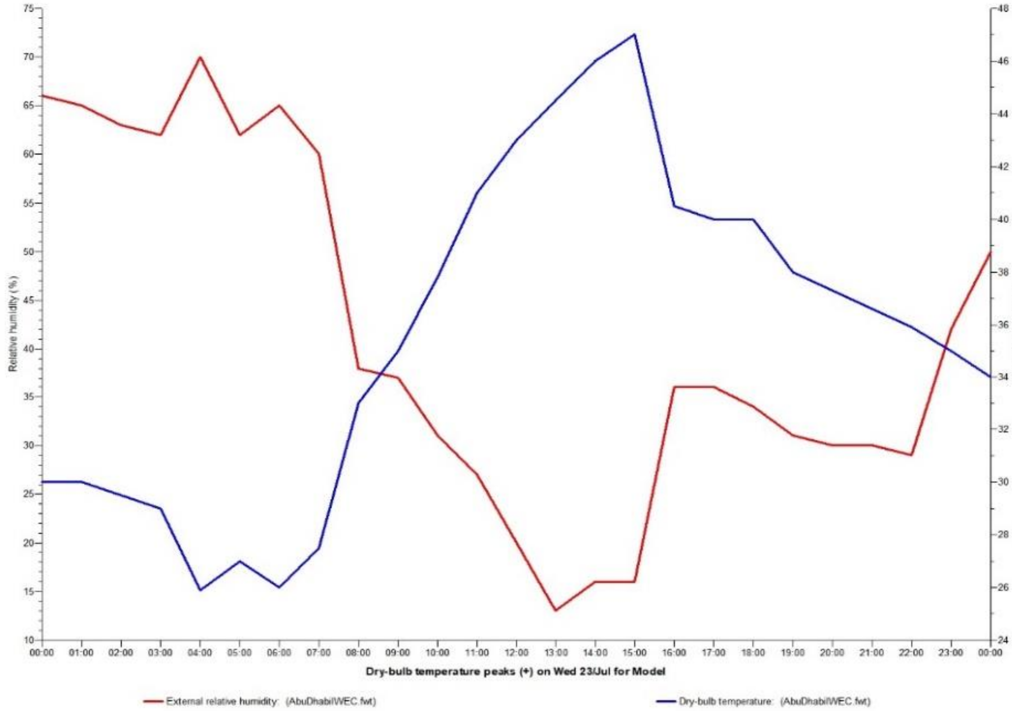


Figure 4.6 Dry bulb temperature and Relative humidity for Sharjah. (IES VE, weather file).

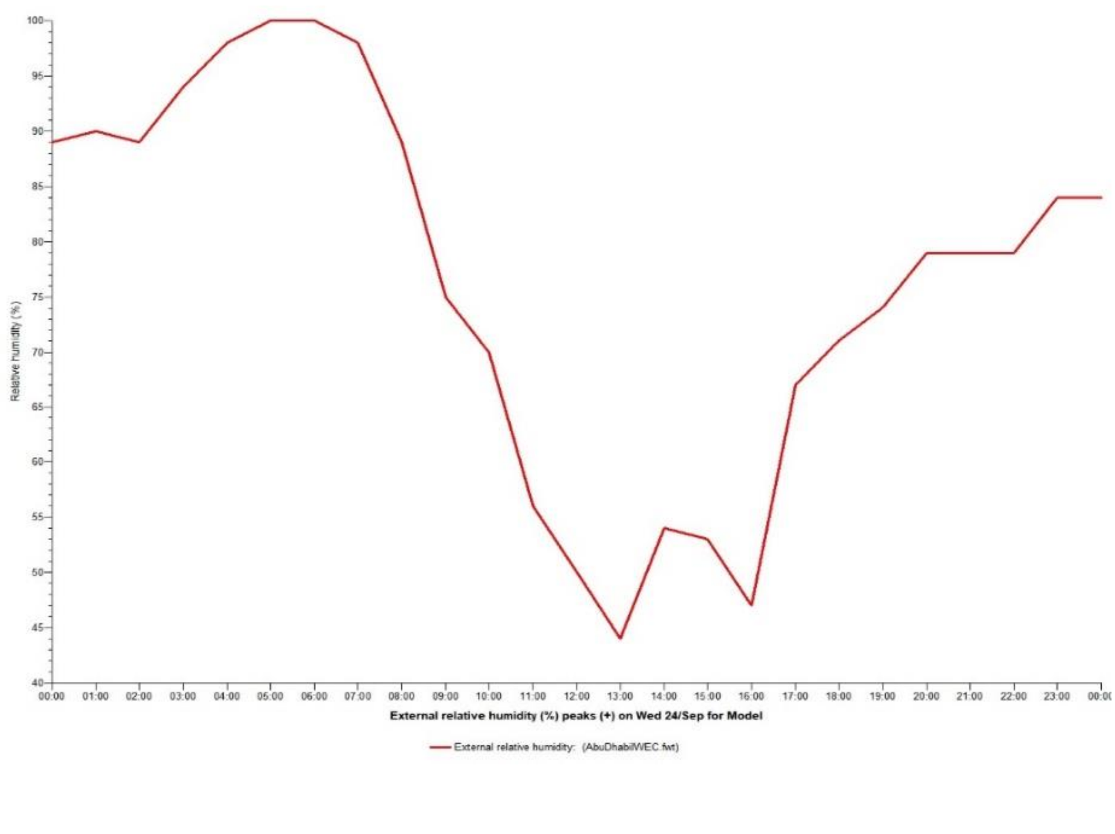


Figure 4.7 Relative humidity for Sharjah in 24th of Sept.. (IES VE, weather file).

4.6 IES VE Validation.

As mentioned in chapter 3 in selected simulation tool section, IES VE is software for energy analysis for the building. IES VE can gives different elements and estimates many dimensions that affect building energy usage like materials, building orientation, cooling and heating system, which is substantial to test building energy. It confirmed its dependability and solidity in the building energy outcomes. (Abu-Hijleh et al. 2017). This view was supported by Elharidi, Tuohy & Teamah (2018) who wrote that academic and technical aspect internationally promote IES VE software energy model simulation. Besides the simulation in IES VE can be examined under many building regulations and scales. According to Negendahl (2015), IES VE is a reliable platform and already confirmed energy software in building performance simulation tools.

Many validations in IES VE were done by comparison between actual electricity bill and base case simulation. As long as the office in this research shares the building (block A) and the cooling units with other companies without installing the British Thermal Unit (BTU) meter, It is difficult to estimate the exact electricity consumption for each company.

As per the reasons above and the available data, the IES VE was used in this research to evaluate some strategies for the HVAC system and compare different simulation results. The variation in results can be achieved by changing the input data for every scenario. For example, different thermostat setpoints and schedules during the day.

4.7 Model Simulation and Scenarios.

4.7.1 Fixed Inputs.

These types of inputs are unchangeable in this research; they are constant from the base case through all scenarios, whether in Summer or Winter season. IES VE contains different templates like construction template, thermal template, and macroflo template. In this research, some inputs in these templates are fixed. Others are varied based on the scenarios created by the researcher. However, this topic can best be treated under the following points:

Construction Template :

In this research, the construction materials are fixed data and are as per the Architectural drawings for the office buildings. Same data was used for the summer and winter scenarios. Table 4.1 shows U value in w/m^{2}k for the building sections.

Table 4.1 shows the thermal behaviour of the building sections.

Building sections	U value w/m^2 k
Internal ceiling /floor	1.5112
External wall	1.0856
External window	5.0784
Internal partition	1.7888
Roof	1.0627

- **Building North Direction:**

The office building orientation was set up as per the building information and site layout drawing. Figure 4.8 shows the north direction in IES VE ModelIT, which used for all scenarios.

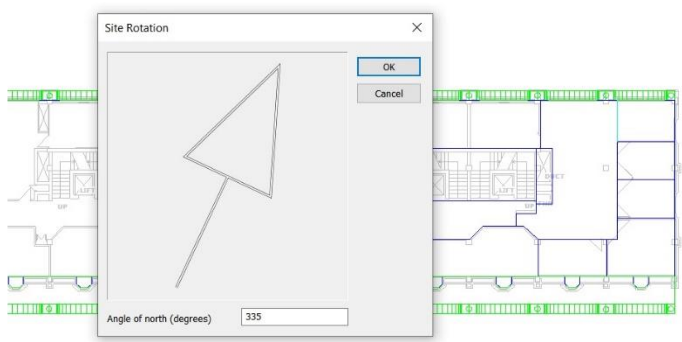


Figure 4.8 Site direction for the office building in Sharjah. (IES VE, ModelIT).

- **Thermal Template:**

  In this research, the thermal template divided into two-part: controlled inputs and fixed inputs. The last one contains internal gains, For example, the number of employee for each zone, and their computers. Also, the interior lights' gain template is considered as a fixed value in all simulations. Each template has its specification. ASHRAE data is used in these templates. For people working in the office as a typical type of paperwork by seating on the desk, sensible heat gain is 70W, latent gain 45W. For the medium-size laptop heat gain is 38 W. The lighting power density for open office space is 10.6 W/m^2 and 12W/m^2 for the private office. Each type of light has its radiant fraction, which is the amount of heat emitted to the surrounding, in this template it is set as 0.68. Each zone in the office building has a different number of employees. Zone A has four occupants, zone 4 has six occupants, and zone 5 has nine occupants. All these types of internal gains have a significant effect on the cooling consumption and indoor CO_2 levels, regardless of the area for each zone. Figures 4.9 and 4.10 show the internal gain templates in IES VE model simulation.

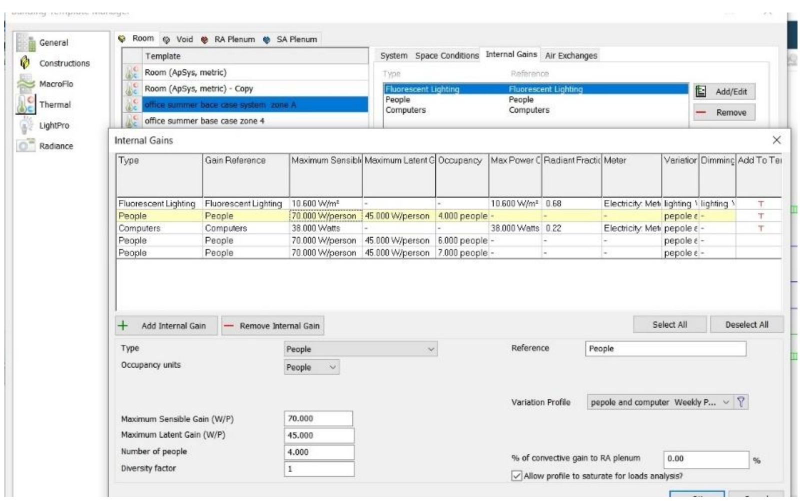


Figure 4.9 People internal gain. (IES VE, Thermal gain).

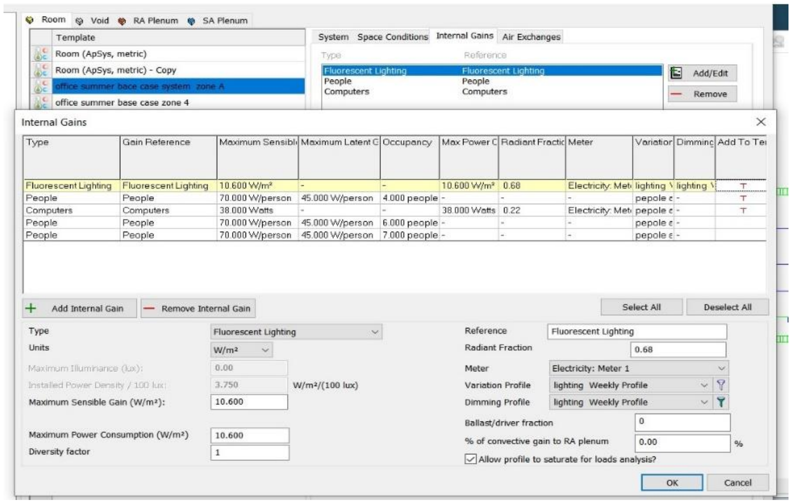


Figure 4.10 Lighting internal gain. (IES VE, Thermal gain).

In order to understand the impacts of the lighting, people and computers on the total energy loads of the building, a profile for each gain was applied through Apache pro. The official work timing in the office building is from 8:00 am to 16:00, but after observation, some employees come early and /or leave late around half an hour or more. Even some sub staff like office boy/cleaner come at 7:20 am. To be more accurate, the lighting timing in the office was set to 7:00 am to 17:00. The full occupied hours for people and the computer times were set to 7:30 am to 16:30, as shown in figures 4.11 and 4.12.

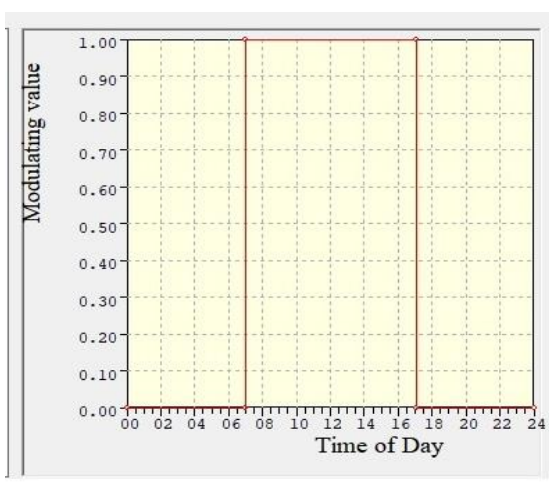


Figure 4.11 Lighting Profile. (IES VE, Apache pro).

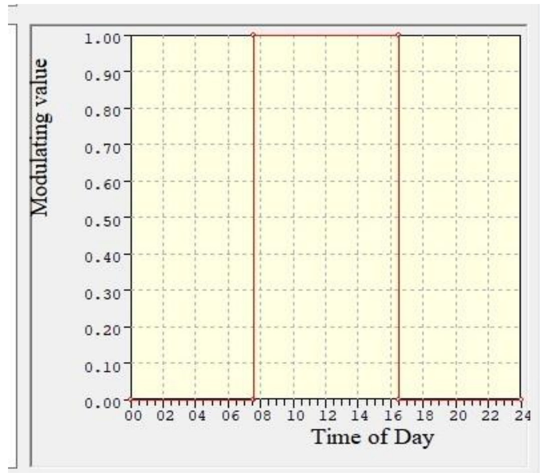


Figure 4.12 People and computer Profile. (IES VE, Apache pro).

As mentioned earlier, the cooling system for the building has a Fresh air handling unit (FAHU) to supply outside fresh air to the office zones. The maximum value of the airflow for the building, which is 1370 l/s was set to the system template in IES VE. In the base case, outside air constantly applies to the zones, whatever is the CO_2 level. This mode was used for all scenarios. But, to upgrade the optimal one to the next level, the CO_2 controller was installed. Besides, a fixed value of infiltration was set as a default value in IES VE, which is 0.25 ACH in all scenarios.

The relative humidity was applied to the humidity control section in the Apache system for the base case and the scenarios. As per AL SA'FAT regulation for the indoor thermal comfort level, the Relative Humidity (RH) is between 30% to 60%. So for the office building, the Maximum RH was set as 60%.

4.7.2 Controlled Inputs.

To evaluate some strategies for the HVAC system and to create different profiles from the base case, cooling system working hours and cooling setpoints are changed. These scenarios depend on the occupants' behaviour inside the spaces. The building system as mentioned earlier is the Fan Coil Unit and Air Handling Unit. The variable inputs were applied in the building system, space condition and air exchange in IES VE thermal template.

Figure 4.13 shows the thermal template in IES VE with the use of the Apache system methodology to create Summer and Winter Season proposals. However, the heating system and domestic hot water in the Apache system were not measured in this study. The heating is set for off continuously.

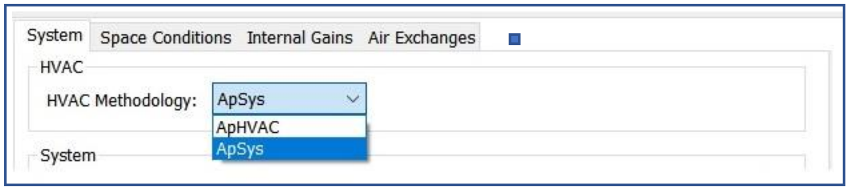


Figure 4.13 Apache System. (IES VE, Building Manager).

4.7.3 Summer and Winter Season Base Case Scenarios.

The information for the base case was collected from site visiting, investigation and talk to the employees. Each zone has its thermostat, and the employees can easily control it. For the summer season, the setpoint for the three thermostats was set to 21^{o}C. The profile for the cooling system in summer set continuously for 24/7. Figure 4.14 shows the applied profile for the cooling system, cooling condition and auxiliary energy. The auxiliary energy section in thermal template measures fans and pumps energy. The zones have no CO_2 sensor, which makes the outside air supply work continuously together with the cooling system, regardless of the internal CO_2 level. For the Winter season, the thermostats for the three zones were set for 24 ^{O}C for working hours only and turned off during the weekend, which is from 7:30 am to 16:30, as shown in figure 4.15.

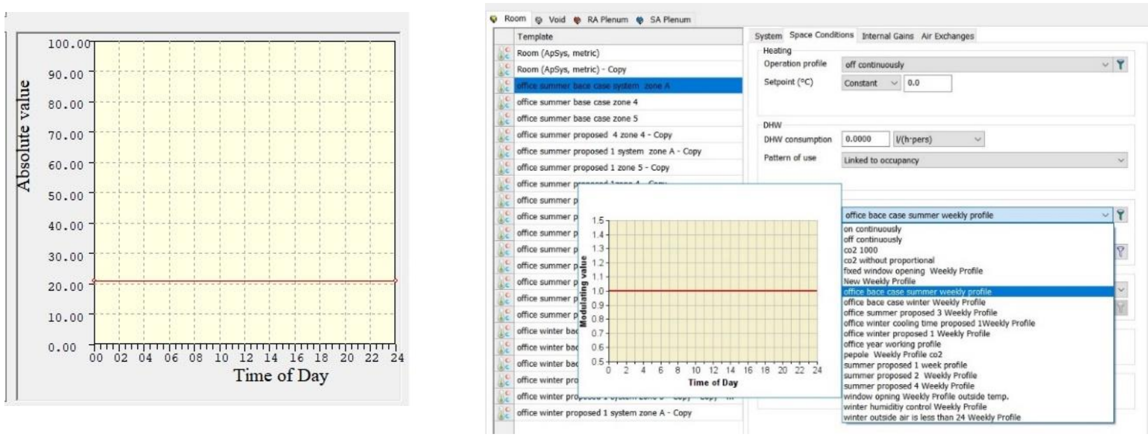


Figure 4.14 Summer Season Base Case Cooling System and Setpoint Profile. (IES VE, Thermal Template).

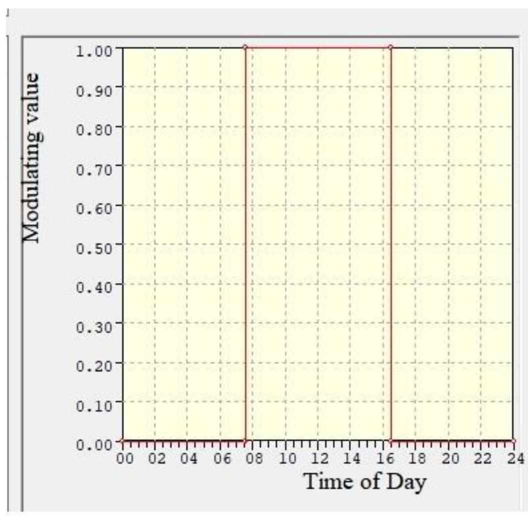


Figure 4.15 Winter Season Base Case Cooling System Profile. (IES VE, Thermal Template).

4.7. 4 Summer Season Scenario 1.

In Summer proposed 1, The cooling system with the fresh air supply system has the same profile as the base case. The whole system works continuously and even in the holidays. However, the thermostat for the three zones has set differently from the base case. In the of outworking hours, the setpoint is 25 ^{o}C, and during working hours the setpoint is 21^{o}C.

Scenario 1 had a strategy of pre-cooling the spaces before peak hours. Figure 4.16. shows the absolute setpoint which was used for the daily profile. Figure 4.17 illustrates the weekly profile for summer scenario 1 as the system works continuously even in the weekends and holidays.

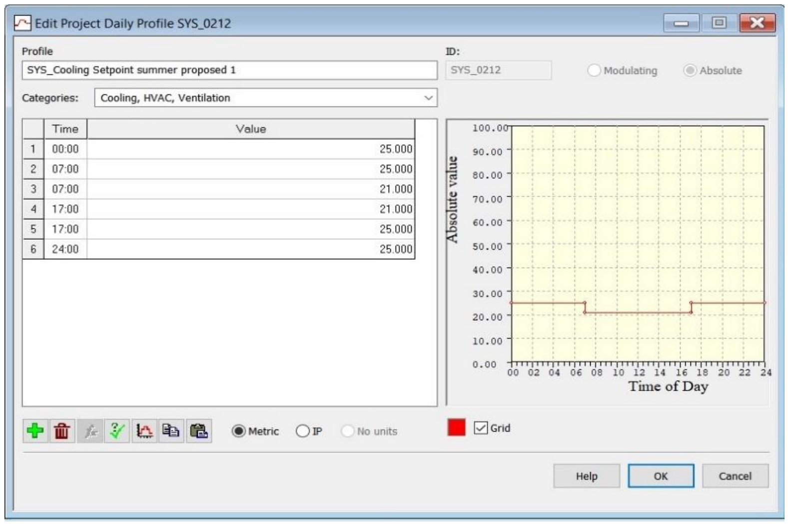


Figure 4.16 Summer Season scenario 1 Cooling System Profile. (IES VE, Apache pro.).

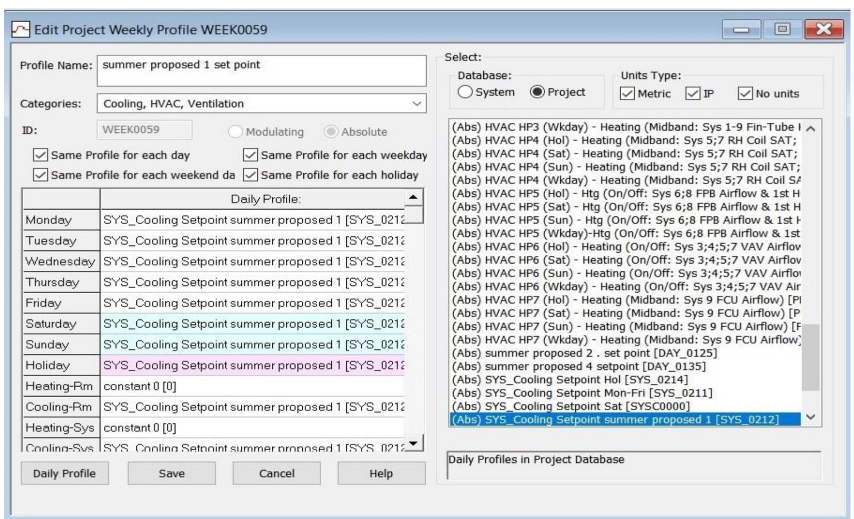


Figure 4.17 Summer Season scenario 1 Cooling System Weekly Profile. (IES VE, Apache pro.).

4.7. 5 Summer Season Scenario 2.

Summer proposed 2, various from the previous scenario. The profile for the cooling system is operating only during working hours and is off during outworking hours. Thus, there is no pre-cooling strategy. Figure 4.18 shows the cooling system profile, which is from 7:00 am to 17:00. And the thermostat setpoint is 21^{O}C within working hours. This scenario applied to understand the difference between this mode and the pre-cooling strategies.

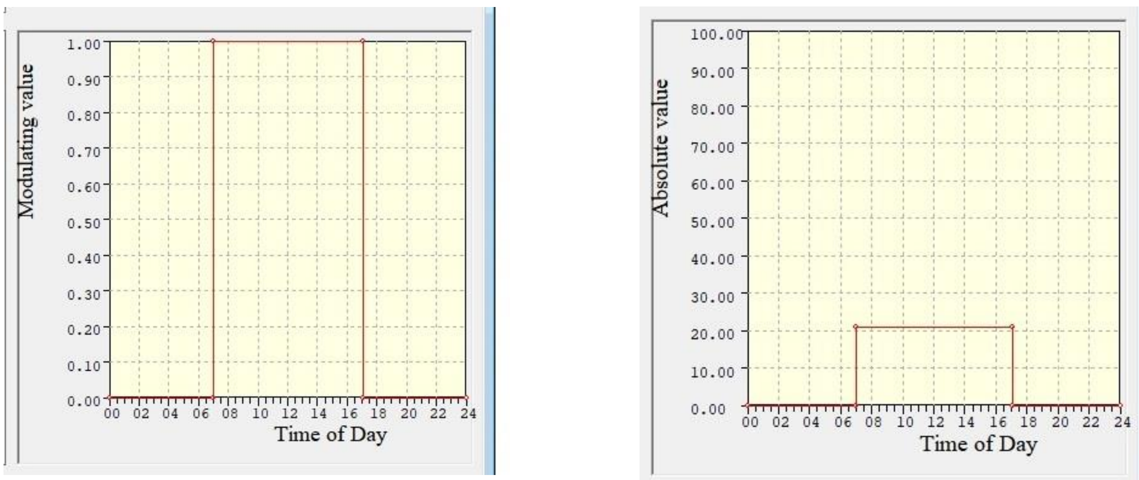


Figure 4.18 Summer Season scenario 2 Cooling System daily Profile and the thermostat setpoint. (IES VE, Apache pro.).

4.7. 6 Summer Season Scenario 3.

In Summer proposed 3, the researcher used various pre-cooling plan. The cooling system is turned on one and a half hour before the usual working time, i.e. 6:00 am and is turned off one and a half-hour after the end of the working time, i.e. 18:00.

The thermostat setpoint is gradually decreased from high to low temperature. From 25 ºC between, 6:00 am to 7:00 am. to 23 ºC between 7:00 to 8:00 am, and then 21 ºC from 8:00 am to 16:00. This process is reversed starting at 16:00 reaching 25 ºC at 18:00, as shown in figure 4.19. Figure 4.20 shows the weekly profile for scenario 3 as this program is in off mode in non-working days.

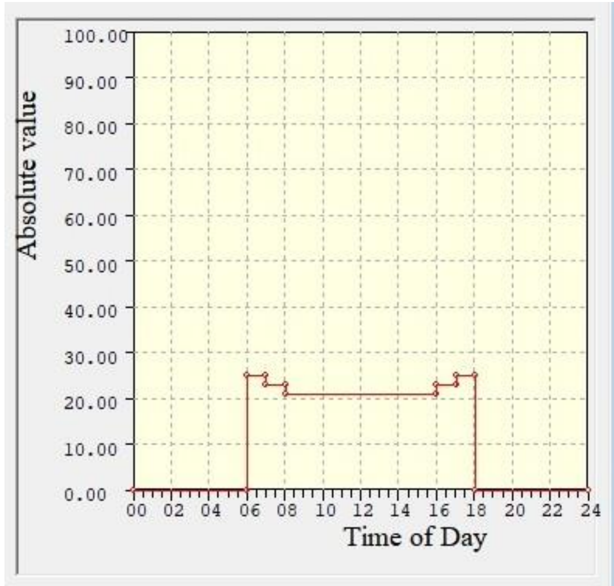


Figure 4.19 Summer Season scenario 3 Cooling System daily Profile. (IES VE, Apache pro.).

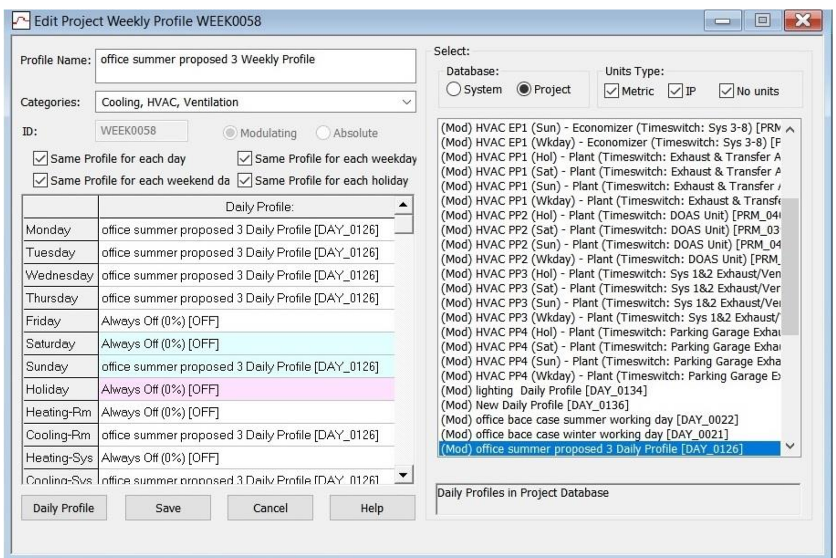


Figure 4.20 Summer Season scenario 3 Cooling System Weekly Profile. (IES VE, Apache pro.).

4.7. 7 Summer Season Scenario 4.

In this scenario, the cooling system profile and the setpoint are changed compared with the base case scenario. The system profile is working 24 hours, so this scenario is built on pre-cooling strategies. However, the thermostat set to 27 ^{O}C in out of working hours and 22 ^{O}C during working hours. Figure 4.21 shows the system module profile and absolute setpoint profile.

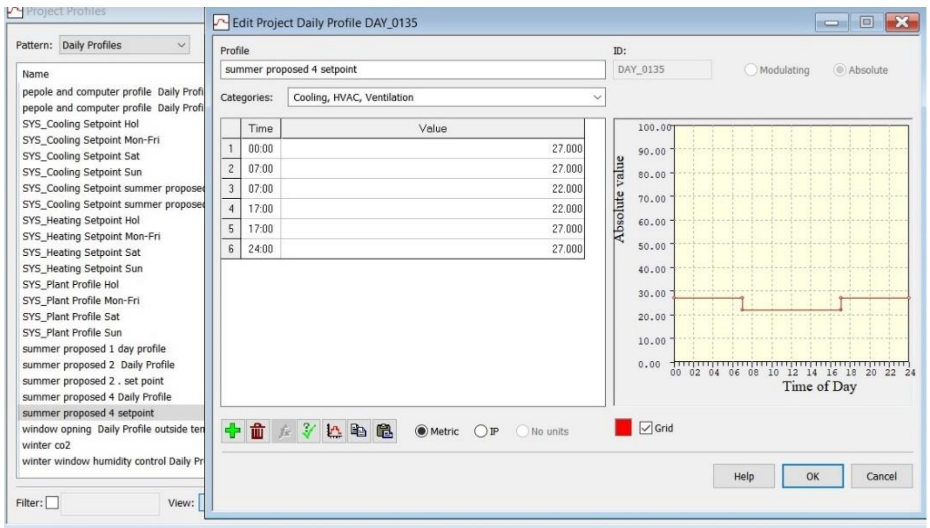


Figure 4.21 Summer Season scenario 4 Cooling System daily Profile.
(IES VE, Apache pro.).

4.7. 8 CO_2 Controller for Summer and Winter Scenarios.

As pointed out earlier in this research, CO_2 is an important driving factor to maintain indoor air quality. CO_2 controller was applied, to improve the air condition inside the office zones. Besides, CO_2 control the amount of outside air as per the level of CO_2 inside the spaces. This procedure is explained in ASHRAE handbook (2017). Accordingly, the working method of every controller is to monitor the changeable amount of the environment elements inside the spaces as per the setpoints.

The main source of the CO_2 inside the office zones is the number of people. Zone A has four employees; zone 4 has six employees, and zone 5 has nine employees. However, these numbers are changeable due to office function and tasks.

CO_2 controller can be set in IES VE through Apache pro and Apache formula. The recommended CO_2 level per ASHRAE inside the space is 1000 part per million (ppm) and as per AL SA'FAT is 800 ppm.

Figure 4.22 shows the formula of CO_2 controller, which is, the controller is on if the CO_2 level in the zone equal or exceeds 1000 ppm without proportion width. As noted earlier in this research, literature review chapter/ programmable thermostat and strategies /mechanical ventilation strategies (CO_2 controller) sections, the type of controller is fuzzy that works as (**on/off)** the amount of the outside supplied air, in other words, the formula uses **(if- then**) mode to maintain the air supply into the spaces. (ASHRAE handbook 2017).

To sum up, **if** the CO_2 level in the office spaces is equal to or more than 1000 ppm, **then** outside air is supplied to the spaces. The airflow stops when the CO_2 inside the office reaches to a certain level below 1000 ppm. These sequences contribute to reducing energy consumption and maintaining the CO_2 level. This process can be more examined in the result section.

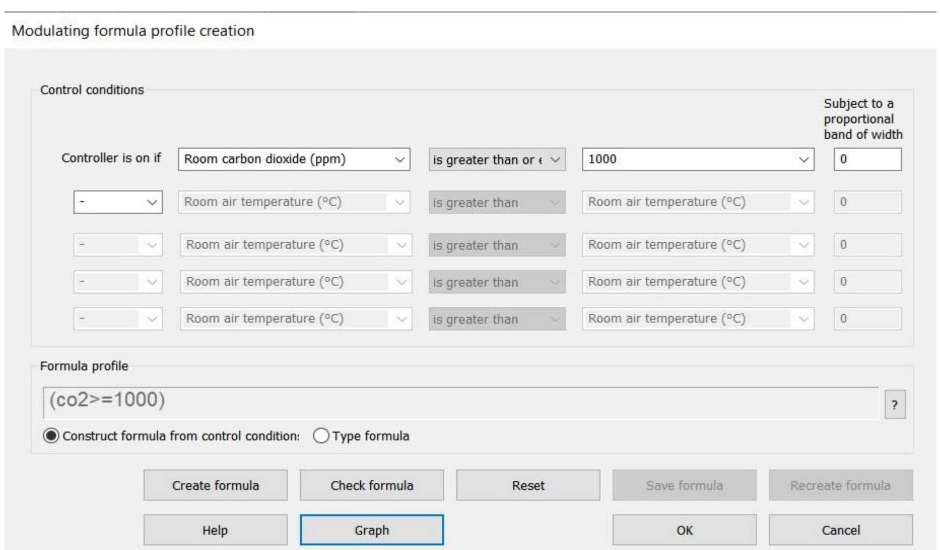


Figure 4.22 CO_2 controller formula profile. (IES VE, Apache pro.).

4.7. 9 Winter Season Scenarios.

Through the visited the office building in February, the researcher noted that when the cooling system was working in some spaces, the window was open. In another visit, the thermostat of zone A was off and for zone 4 was on. Besides, all the doors between the zones were open. This act was because of the spaces become overcooled and occupants unsatisfaction. Such behaviours cause energy waste.

Winter scenario introduces natural ventilation to the spaces; it combines the natural and mechanical cooling system. As mentioned in chapter two/ mixed-mode ventilation**,** this type call hybrid ventilation. However, this scenario can be best applied by programming the thermostat to work in a certain time and monitor the opening of the window.

Figure 4.23 shows the control formula for the opening, which has a link with the outside weather condition. IES VE weather file from ASHRAE climate design provides all the data that may use in this formula. However, this formula has to achieve two conditions to reach the thermal comfort level for the occupants. These conditions are air temperature and Relative Humidity (RH).

The window will open when the inside air temperature is greater than the outside air temperature, and when the outside relative humidity is less than 60% as per AL SA'FAT comfort level. Also, the type of the window opening and its profile was identified in Macroflo energy section in IES VE. The windows schedule to open from 8:00 am to 11:00 am and the cooling system starts from 11:00 am to 16:30. For scenarios summaries table (Check Appendix A).

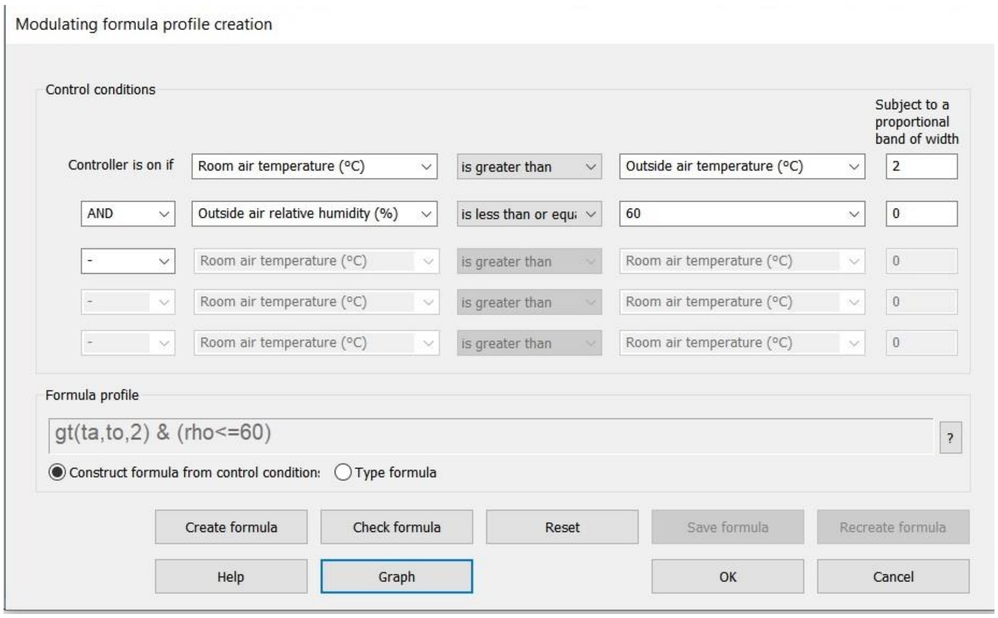


Figure 4.23 Window opening controller formula profile. (IES VE, Apache pro.).

Chapter 5 Results and Discussion

5.1 Introduction.

This part of the research illustrates the findings which emerged from the IES VE simulation method. This chapter is divided into three sections. The first one is about the results of the Summer and Winter Season base case. The second section discusses the findings of the proposed scenarios from cooling loads aspect and indoor temperature. Different dates and times are offered from the scenarios to explain the indoor air temperature. The findings are compared with the base case to reach the best design. The third section is about the result of the upgraded system with the CO_2 controller. The comparison between the scenarios is done under essential considerations like total energy saving, reduce peak hours, thermal comfort and indoor air quality, also, under ASHRAE standards and Al Sa'fat.

5.2 Summer and Winter Base Case.

As mentioned in the model simulation chapter, the Summer base case strategy is different than Winter base case. As per the base case, the Summer months are from (March-end of November). And Winter months are from (December- to end of February). Each zone has its energy consumption regarding the various internal gains. Table 5.1 presents the results obtained from base case IES VE simulation for Sensible cooling loads during the year in MWh for the three zones. The overall load are 32.5076MWh per year. And for the Summer season, the overall is 32.1503 MWh, as for zone A is 12.6036 MWh, for zone 4 is 11.6175 MWh, and for zone 5 is 7.9292 MWh. There is a clear tends in increasing cooling consumption in summer months compared with winter months. For example, June, July and August have the highest consumption. However, there are several possible explanations for this result.

As per the Sharjah weather file, the dry bulb temperature and the relative humidity is above the comfort level during the summer months. Al Sa'ft regulation introduces the level of thermal indoor occupants well-being is (22.5ºC - 25.5 ºC). (Al Sa'fat, Dubai green building 2016).Generally, cooling load means how much the HVAC system capacity to carry away the heat from this building. System consumption relies on the outside weather situation and inside internal gain. Heat transfer from outside to the building is affected by many factors.

For example, building design, materials type, glazing technologies and building direction. Besides, internal gains, like building function and number of people, have a significant impact on the cooling system. Salameh et al. (2020). Overall, weather conditions, building design and internal behaviour all those factors have a significant impact on the cooling loads. In this research, some factors have a positive effect on the building thermal behaviour like orientation and the shading area caused by the canopy, which may assist in cooling down the building. These factors were examined in the previous section in IES VE Suncast. However, the thermostat for the base case is set for 21 C for whole summer months, which may not be the best scenario to achieve energy efficiency and thermal comfort at the same time.

Table 5.1 Sensible cooling loads during the year for summer months (Mar- Nov) and winter months (Jan, Fab and Dec). (IES VE, Vista pro. /Room result.).

	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)
Date	summer base case/zone 5	summer base case/zone 4	summer base case/zone A
Mar 01-31	0.4702	0.6809	0.6189
Apr 01-30	0.7047	1.0327	1.0666
May 01-31	0.9439	1.3944	1.5406
Jun 01-30	1.0433	1.5398	1.7418
Jul 01-31	1.1584	1.7129	1.9504
Aug 01-31	1.1637	1.7124	1.9598
Sep 01-30	1.023	1.4975	1.6656
Oct 01-31	0.8375	1.2145	1.2752
Nov 01-30	0.5844	0.8323	0.7848
Summed total	7.9292	11.6175	12.6036
Summer months sensible cooling loads 32.1503 MWh			

Date	winter base case/zone 5	winter base case/ zone 4	winter base case/zone A
Dec 01-31	0.0565	0.0937	0.0414
Jan 01-31	0.0092	0.0231	0
Feb 01-28	0.0363	0.0725	0.0247
Summed total	0.1019	0.1893	0.0662
Winter months sensible cooling loads 0.3574 MWh			
Total sensible cooling loads per year 32.5076 MWh			

Figure 5.1 explains the correlation between the dry resultant temperature and sensible cooling loads for zone 4 in 24th of July as an example for the base case. Radiant temperature is the heat that emits from objects inside the room. ASHRAE Handbook (2017). The dry resultant temperature in IES VE vista pro is the amount of air temperature and mean radiant temperature inside the room. (IES VE 2020).

Besides, figure 5.2 confirms that the cooling load is associated with the increase outside temperature and internal gain. As office timing is from (7:30 am – 16:30) when the occupants need the cooling system to reach the comfort level.

However, the system keeps working 24 hours with the setpoint 21^{o}C, which is energy waste. Also, The dry resultant temperature is under 22.5 ^{o}C, and the air temperature is 21 ^{o}C both are lower than the comfort level.

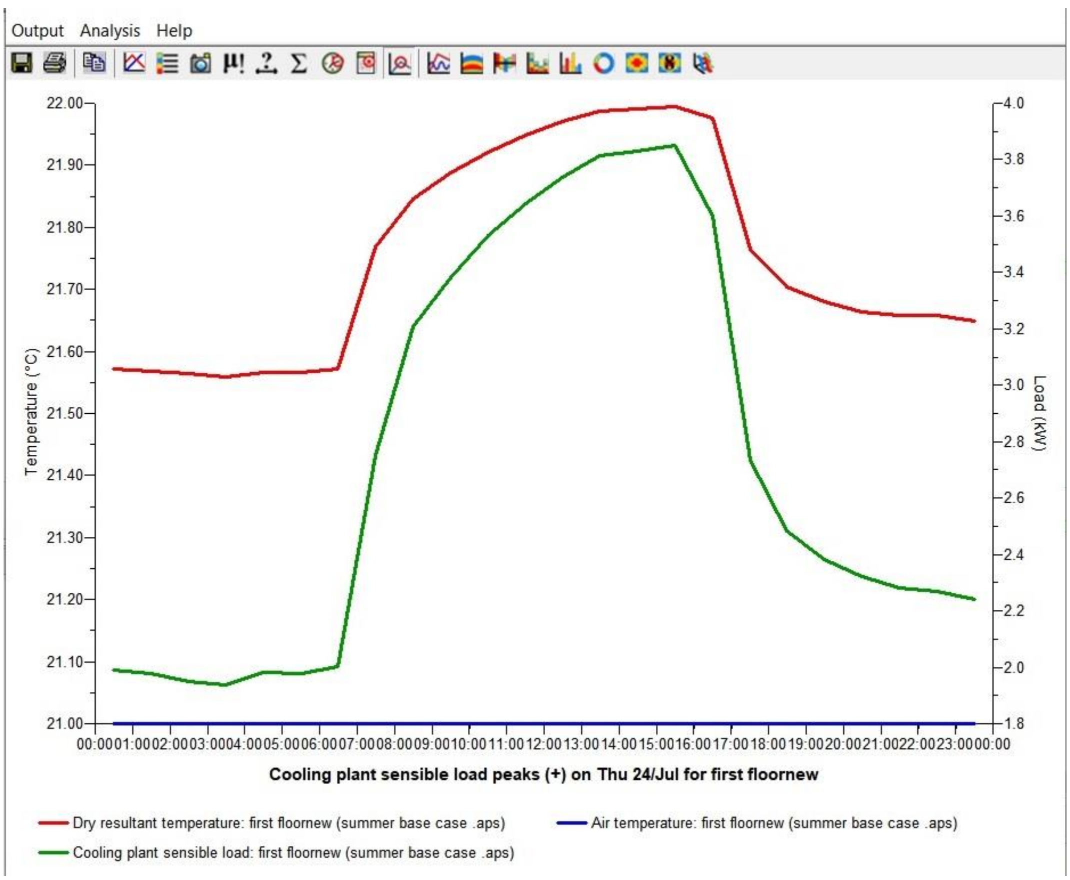


Figure 5.1 Sensible cooling loads. (IES VE, Vista pro. /Room result.).

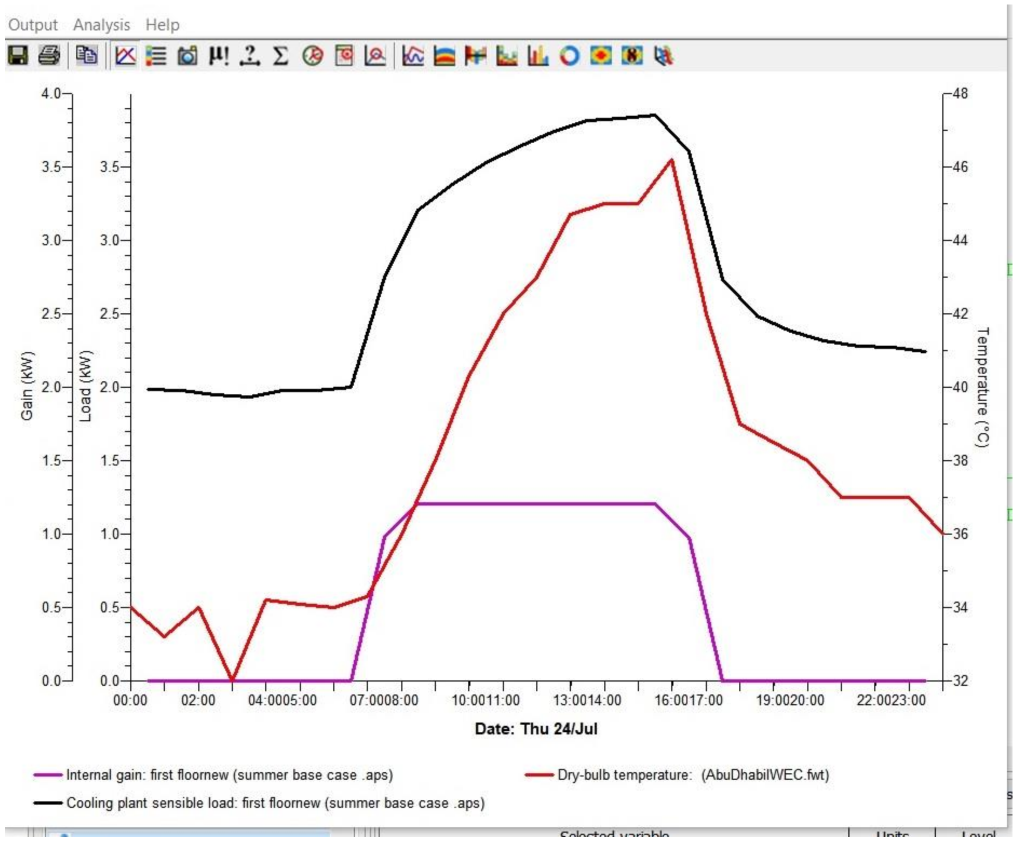


Figure 5.2 internal loads. (IES VE, Vista pro. /Room result.).

5.3 Proposed Scenarios.

5.3.1 Summer Scenario 1.

In summer scenario 1, the cooling system operates for 24 hours the same in base case but with a different setpoint. In out of working hours the setpoint is 25 ºC and 21 ºC in working hours. Table 5.2 below presents the simulation data on sensible cooling loads for the Summer months. It shows a significant decreasing in the sensible cooling loads compared with summer months base case. Just reset the thermostat to 25 C, can achieve a reduction in zone A from 12.6036 MWh to 10.1727 MWh that is 19.29%, and for zone 4 from 11.6175 MWh to 8.8716 MWh that is 23.64%, and for zone 5 from 7.9292 MWh to 5.8812 MWh that is 25.83%. The overall reduction is 22.47 %. This view was supported by Aghniaey & Lawrence (2018) build on their investigation in other research papers.

They claim that most of the building is using under required air temperature setpoint, which any rising in the setpoint has a significant impact on the total energy saving in the building. Besides, Hoyt et al. (2009 in Aghniaey & Lawrence 2018) found that rise in setpoint from 24 ^{o}C to 25 ^{o}C can economise 7-15% and if rise to 28 C the reduction can reach to 35-45% from the total energy.

Table 5.2 Sensible cooling loads during Summer months. (IES VE, Vista pro. /Room result.).

	Cooling plant sensible load (MWh)	**Cooling plant sensible load (MWh)**	**Cooling plant sensible load (MWh)**
	first floornew/zone5	first floornew/zone 4	first floornew/zone A
Date	summer 1 .aps	summer 1 .aps	summer 1 .aps
Mar 01-31	0.4405	0.6699	0.6436
Apr 01-30	0.5501	0.838	0.8683
May 01-31	0.6734	1.0287	1.1685
Jun 01-30	0.7294	1.1031	1.3642
Jul 01-31	0.8279	1.2484	1.5596
Aug 01-31	0.8325	1.2473	1.5692
Sep 01-30	0.7178	1.0762	1.292
Oct 01-31	0.6192	0.9302	0.9883
Nov 01-30	0.4904	0.7297	0.7191
Summed total	5.8812	8.8716	10.1727
Summed total for the three zones 24.9255 MWh			

However, figure 5.3 presents the dry resultant temperature in zone A on the 21st of July, which is still within the thermal comfort limit. In out of working hours around 25-25.5 ^{o}C and in working hours is around 22.5 ^{o}C. And the highest level of cooling consumption is between 7:30 am to 16:30 due to the internal gains which are the number of occupants, computers and other equipment and lighting.

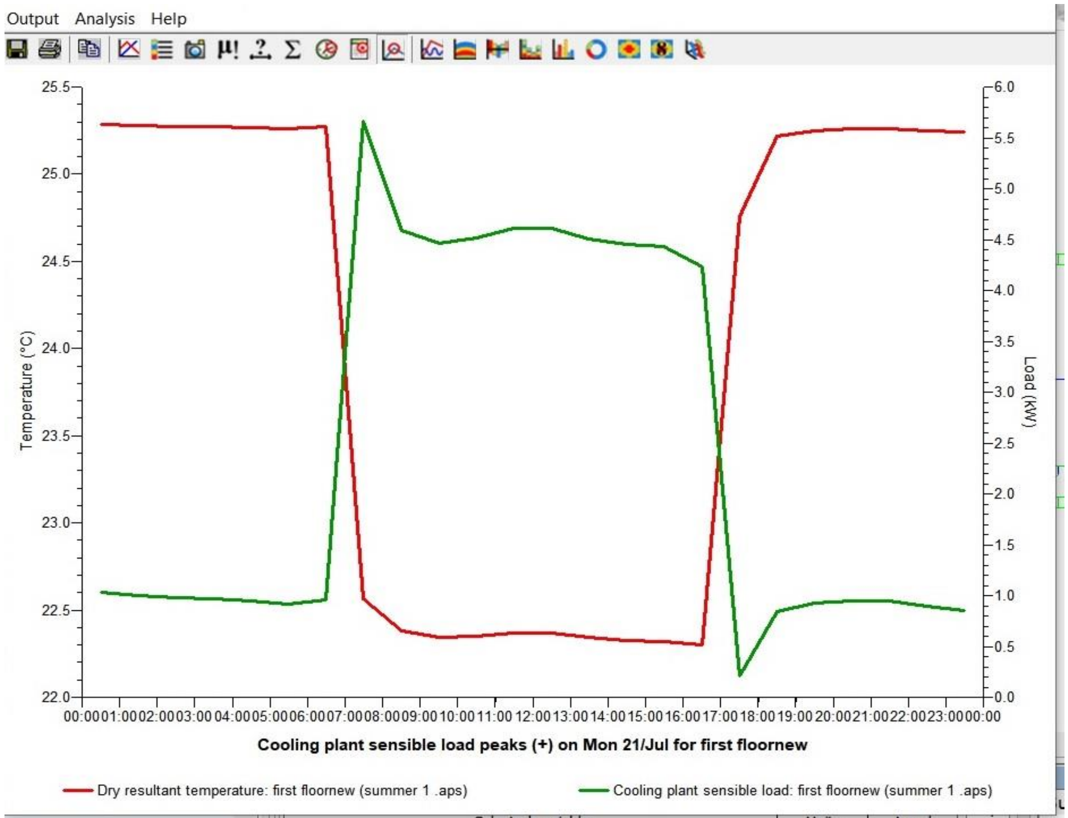


Figure 5.3 dry resultant temperature and cooling loads in 21st of July . (IES VE, Vista pro. /Room result.).

5.3.2 Summer Scenario 2.

Scenario 2 is different than scenario 1 for Summer months (March- November). It depends on the usual turn on/off for the zones thermostat during the occupy hours for the office building which is from 7:00 am to 17:00. So the system turns off in out of working hours and weekend days that are Friday and Saturday as per office base case operating schedule. Table 5.3 provides sensible cooling loads consumption for Summer scenario 2. It is apparent from this table is the considerable lowering in cooling loads compared with the base case for the three zones. For zone A, the reduction is from 12.6036 MWh to 7.4773 MWh that is around 40.67%. Zone 4 is from 11.6175 to 6.8431 MWh that is 41.1%, and for zone 5 is from 7.9292 to 4.5667 MWh, that is 42.41%. The overall reduction for the three zones is 41.25%.

Table 5.3 Sensible cooling loads during Summer months. (IES VE, Vista pro. /Room result.).

	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)
	zone/5	/zone 4	/zone A
Date	summer 2 .aps	summer 2 .aps	summer 2 .aps
Mar 01-31	0.3048	0.4515	0.4049
Apr 01-30	0.4292	0.6436	0.6644
May 01-31	0.5122	0.7755	0.8562
Jun 01-30	0.6025	0.9113	1.0448
Jul 01-31	0.6587	0.9943	1.1506
Aug 01-31	0.6209	0.9344	1.0877
Sep 01-30	0.588	0.8792	0.996
Oct 01-31	0.4857	0.7216	0.765
Nov 01-30	0.3646	0.5317	0.5077
Summed total	4.5667	6.8431	7.4773
Summed total for the three zones 18.8871 MWh			

Figure 5.4 is a notable example of summer scenario 2. It shows the cooling sensible load, air temperature, and dry resultant temperature for zone A on the 27th of July. At 12:06 pm, the dry resultant temperature reaches 22.87 ^{o}C, which is still within the thermal comfort level. Most of the studies about the HVAC system has a section for thermal comfort. In reviewing the literature, the indoor thermal comfort for occupants depends on many factors as per ASHRAE 55.for example, clothing insulation and metabolic rate.

As noted by Silva, Ghisi & Lamberts (2016), and referring to the literature review chapter/thermal comfort section, some of the factors that affect thermal comfort can be controlled and changed during the year in the Summer and Winter season. For example, clothing insulation which was set as 0.57 clo., and the metabolic rate which has different estimates relating to the occupants' activities or space functions. However, in this research, the comfort setting can adjust through IES VE comfort conditions. For example, the clothing insulation was set as a default which is 0.69 clo.

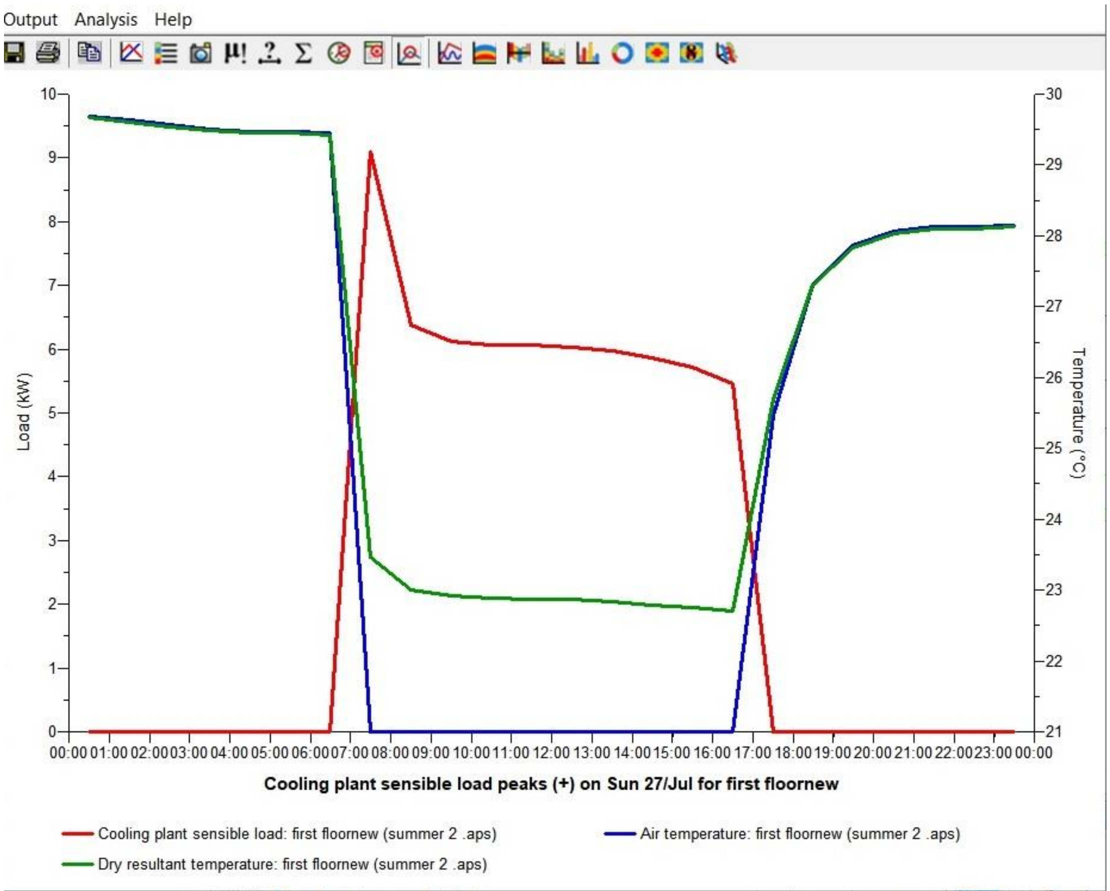


Figure 5.4 dry resultant temperature and cooling loads in 27th of July . (IES VE, Vista pro. /Room result.).

5.3.3 Summer Scenario 3.

Referring to the simulation module section, the system in summer scenario 3 works one and a half- hour before/after the usual office working hours with different setpoints. Table 5.4 presents sensible cooling loads. It appears almost similar to scenario 2. As in zone A, the cooling load reduction is from 12.6036 KWh to 7.2652 KWh around 42.36%. In zone 4 the reduction is from 11.6175 KWh to 6.5069 KWh around 43.99% and zone 5 from 7.9292 KWh to 4.3522 KWh around 45.11%. The overall lowering for the three zones compared with the base case is 43.63%.

Table 5.4 Sensible cooling loads for Summer scenario 3. (IES VE, Vista pro. /Room result.).

	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)
	first floornew/zone5	first floornew/zone4	first floornew/zoneA
Date	summer 3 .aps	summer 3 .aps	summer 3 .aps
Mar 01-31	0.2881	0.4332	0.3935
Apr 01-30	0.4039	0.6075	0.6316
May 01-31	0.4853	0.7326	0.8241
Jun 01-30	0.5768	0.8672	1.0244
Jul 01-31	0.6355	0.9527	1.1357
Aug 01-31	0.6017	0.8983	1.0778
Sep 01-30	0.561	0.8329	0.9691
Oct 01-31	0.4574	0.6792	0.7271
Nov 01-30	0.3425	0.5033	0.4819
Summed total	4.3522	6.5069	7.2652
Summed total for the three zones 18.1243 MWh			

Figure 5.5 shows the sensible cooling loads and air temperature on the 27th of July for zone 4 as an example for scenario 3. It appears that sensible loads gradually rise associates with the decrease in the air temperature setpoints to reach the thermal comfort level. The air temperature in the space reaches to 21^{o}C. The dry resultant is 22.43 ^{o}C around 12:07 pm, which is within thermal comfort as per Al Sa'fat.

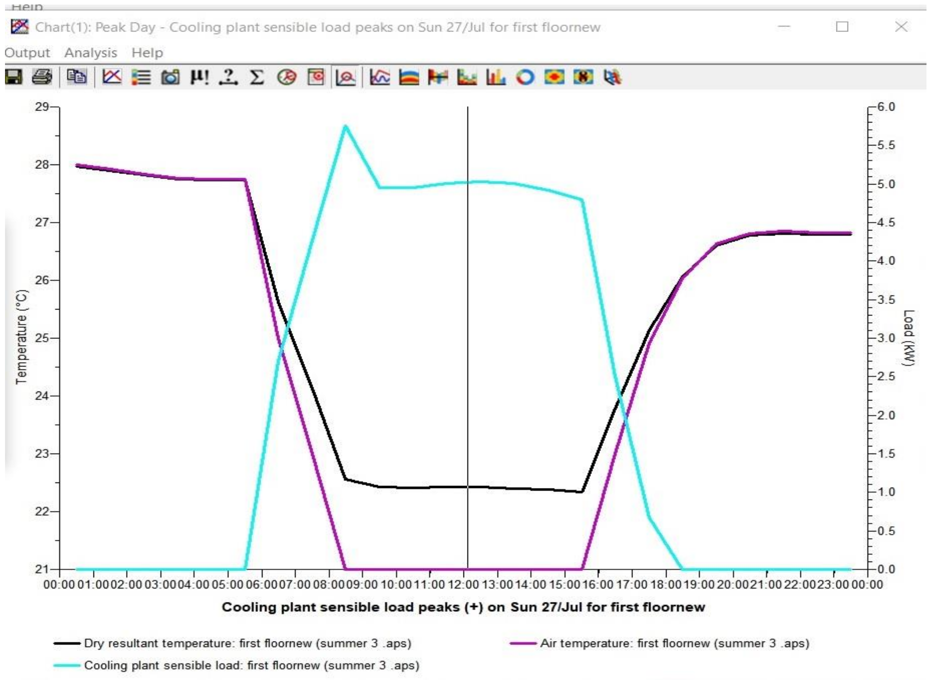


Figure 5.5 dry resultant temperature and cooling loads in 27th of July . (IES VE, Vista pro. /Room result.).

5.3.4 Summer Scenario 4.

Scenario 4 is comparable to scenario 1 but different air temperature setpoints. The system works 24 hours. In out of working hours the thermostat set on 27 ^{o}C and in working hours 22^{o}C. Table 5.5 shows sensible cooling loads for summer months. The total energy for the three zones is 22.761 MWh. The reduction is around 29.20% compared with the base case scenario of summer months.

Table 5.5 Sensible cooling loads for Summer scenario 4. (IES VE, Vista pro. /Room result.).

	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)	Cooling plant sensible load (MWh)
	first floornew/zone5	first floornew/zone 4	first floornew/zone A
Date	summer 4 .aps	summer 4 .aps	summer 4 .aps
Mar 01-31	0.4036	0.6207	0.6176
Apr 01-30	0.5129	0.7886	0.8398
May 01-31	0.6302	0.9699	1.0858
Jun 01-30	0.6772	1.0334	1.1772
Jul 01-31	0.738	1.1224	1.3272
Aug 01-31	0.734	1.11	1.3237
Sep 01-30	0.6657	1.0055	1.1354
Oct 01-31	0.5808	0.8794	0.9521
Nov 01-30	0.454	0.6815	0.6946
Summed total	5.3964	8.2113	9.1533
Summed total for the three zones 22.761 MWh			

Figure 5.6 presents the situation inside zone 4. The air temperature at 12:11 pm. on the 24th of July is 22 ^{o}C as per the thermostat's setpoint. The dry resultant temperature at the same time is 23.10 ^{o}C that is still within the thermal comfort level. The 24th of July is peak day as per the IES VE within the Summer months (March- November).

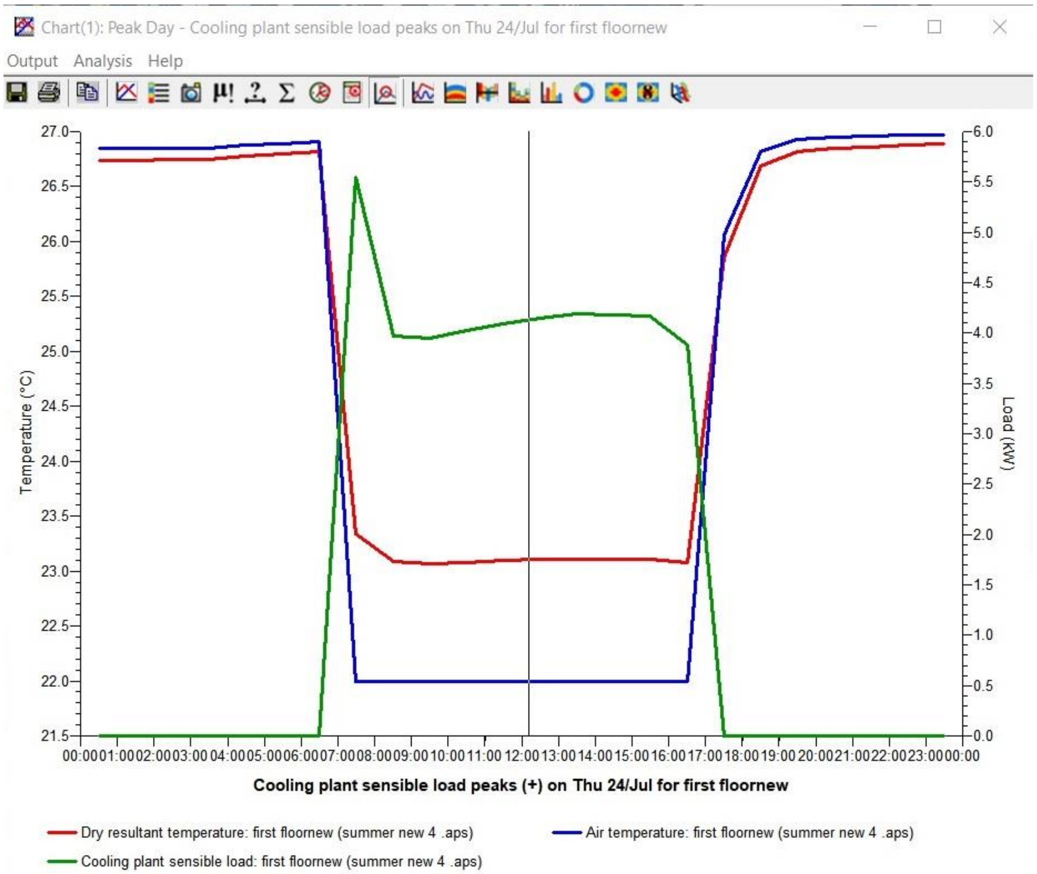


Figure 5.6 dry resultant temperature and cooling loads in 24thof July. (IES VE, Vista pro. /Room result.).

5.4 Comparison Between Summer Scenarios regarding the Cooling Loads.

This research is to evaluate some strategies relating to energy efficiency in the office building. It can be done by scheduling the space thermostat associate with the occupancy behaviour. Figure 5.7 and Table 5.6 present cooling loads results in KWh on the 21st of July for zone 4 in the office building as an example to understand the cooling loads.

This example is to recognise how the cooling loads are changing relating to the different scenarios in Summer months. For scenarios 1 and 4 have the same pattern that is pre-cooling but with various thermostat setpoints and the system works for 24 hours.

Scenario 3 also has a pre-cooling mode with the system operates one and a half hour before and after office time. However, the system operation in scenario 2 is just within office time. As shown in figure 5.7 associate with the numbers in table 5.6, the difference is notable in the first hour of the office time.

This result may be explained by the fact of the pre-cooling mode which helps to shift the loads from the peak point in the first hour of the internal gain. It is likely that the highest number in the table below is considered as a peck point. Scenario 2 has the highest peak hour cooling load; it reaches to 6.67 KWh on 7:30 am.

Surprisingly, system consumption in scenario 4 is more than scenario 1 on 7:30 am in contrast to the setpoints of the two scenarios. It seems possible these results are due to pre-cooling thermostat setpoints, as scenario1 is set to 25 ^{o}C and 21 ^{o}C during working hours, and scenario 4 is set to 27 ^{o}C in out of working hours with 22 ^{o}C during working hours. Furthermore, the cooling load with setpoint 27 ^{o}C is zero consumption in some days like on 21st of July; this may be related to normal room temperature (without cooling system) less than the setpoint 27 ^{o}C. These findings for scenario 4 are not helping to achieve the goal of the pre-cooling mode, which is load shifting from the peck hours.

On the other hand, Scenario 3 has one and a half hour pre-cooling before the space being occupied, its peck hour shifted to 8:30 am which is 5.46 KWh that is comparable to the to scenario 1 and 4. The same process happened with zone A and 5. In zone A, the peak load hour reach to 7.98 KWh in scenario 2. (Check Appendix A).

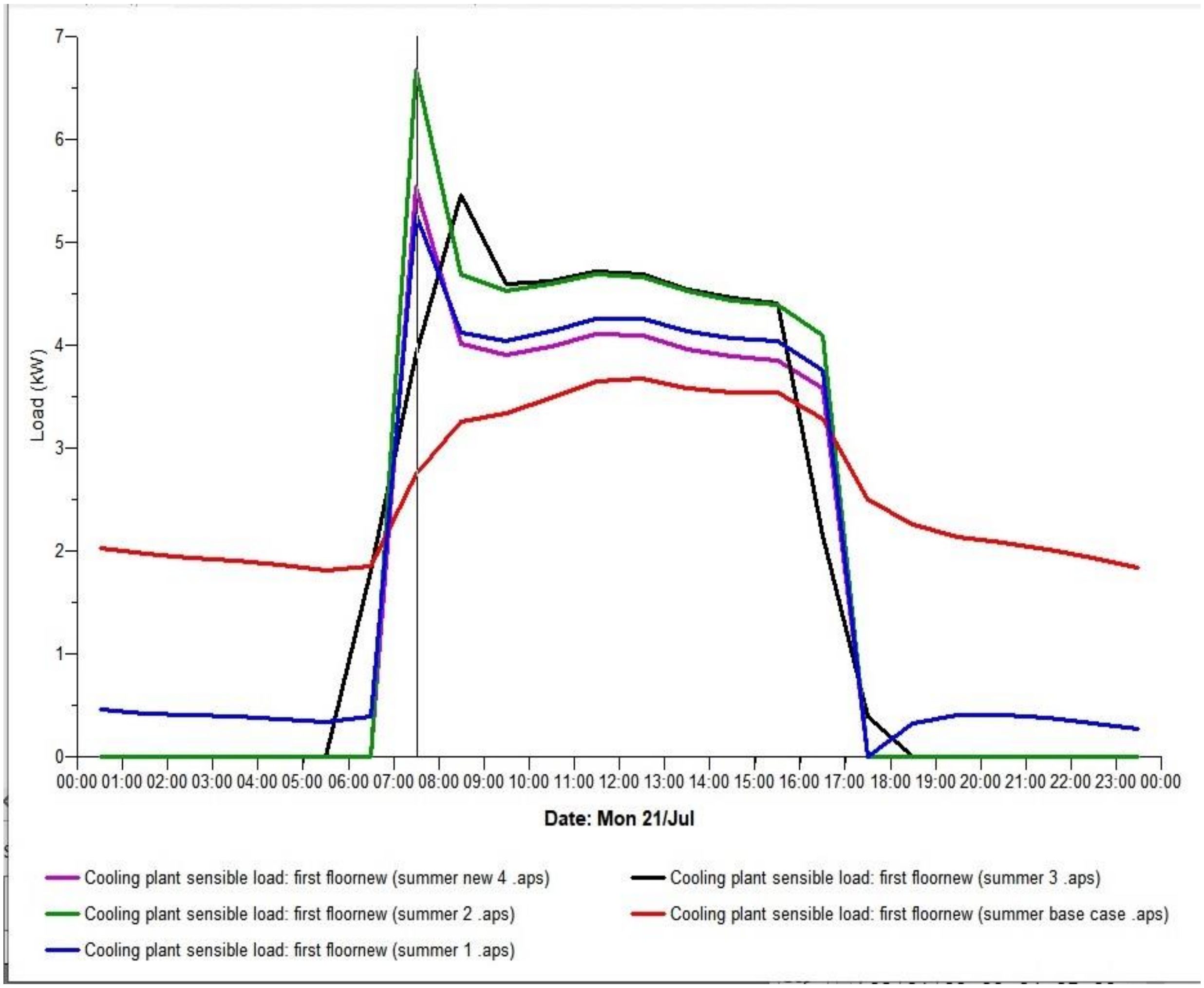


Figure 5.7 cooling loads for the scenarios in 21st of July. (IES VE, Vista pro. /Room result.).

Table 5.6 Sensible cooling loads for Summer scenarios. (IES VE, Vista pro. /Room result.).

Cooling plant sensible load (kW)						
first floornew/Zone4						
Date	Time	summer 4 .aps precooling 27 °c Cooling 22 °c	summer 3 .aps precooling 25,23 °c Cooling 21 °c	summer 2 .aps pre-cooling off cooling 21 °c	summer 1 .aps pre-cooling 25 °c cooling 21 °c	Bace case cooling 21°c
Mon, 21/Jul	0:30	0	0	0	0.455	2.022
	1:30	0	0	0	0.424	1.971
	2:30	0	0	0	0.4	1.927
	3:30	0	0	0	0.391	1.9
	4:30	0	0	0	0.372	1.864
	5:30	0	0	0	0.342	1.817
	6:30	0	1.812	0	0.396	1.854
	7:30	5.535	3.902	6.67	5.27	2.745
	8:30	4.019	5.46	4.688	4.117	3.253
	9:30	3.903	4.599	4.524	4.037	3.335
	10:30	3.993	4.623	4.59	4.138	3.492
	11:30	4.106	4.711	4.686	4.257	3.649
	12:30	4.095	4.685	4.663	4.255	3.677
	13:30	3.966	4.544	4.523	4.135	3.586
	14:30	3.893	4.457	4.438	4.067	3.544
	15:30	3.855	4.407	4.388	4.035	3.535
	16:30	3.578	2.146	4.1	3.763	3.286
	17:30	0	0.386	0	0	2.493
	18:30	0	0	0	0.326	2.262
	19:30	0	0	0	0.399	2.133
	20:30	0	0	0	0.407	2.077
	21:30	0	0	0	0.383	2.015
	22:30	0	0	0	0.328	1.927
	23:30	0	0	0	0.274	1.84

The scenarios and the findings of the current study are consistent with those of Turner, Walker & Roux (2015), who examined the pre-cooling mode on the residential building. The study determined the maximum using hours of the cooling system. The pre-cooling programs were used various setpoints in a different time, for example, 25ºC, 26.7 ºC, and 22.2 ºC. The pre-cooling modes were set for 24 hours on high setpoints but, before the peak time the thermostat turns on to less setpoint like 22.2. The outputs of scenarios show a significant decrease in shifting peak loads. However, the overall consumptions per year are increased by 60% because of the cooling system turned on for 24 hours.

The research by Turner, Walker & Roux (2015) can be confirmed by the current study, as figure 5.8 presents the cooling loads' chart for the summer months scenarios. The pre-cooling mode scenarios (1and 4) that operate for 24 hours have a significant energy consumption compared with scenario 2. Interestingly, scenario 3 has a notable reduction in total energy; this result may be due to one and a half hour only for pre-cooling and with different setpoints. Furthermore, scenario 3 is less than scenario 2; this rather contradictory result may be due to the air temperature setpoint for the first and last half-hour of the office time, which is 23ºC. Overall, these results from the consumption view indicate that Summer scenarios can achieve from (22.47% -43.63%) reduction in cooling loads. All the scenarios can be implemented in the office zones. However, scenario 2 and 3 can perform the most reduction in cooling loads. Interestingly, scenario 3 has the most benefit in the pre-cooling plan by shifting loads from the peck hour at the same time, reduce the overall consumption.

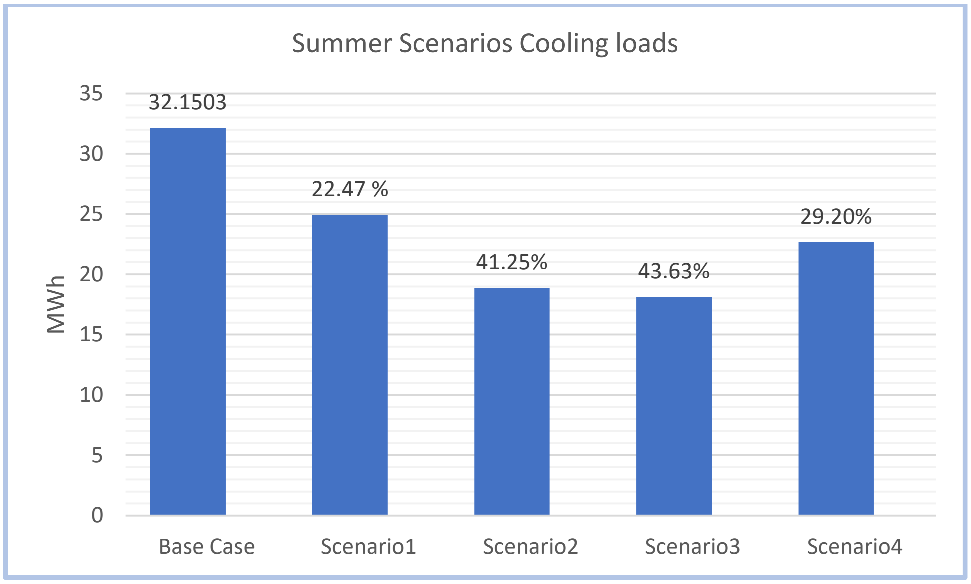


Figure 5.8 Comparison between the summer scenarios in cooling loads reduction.

However, Clark et al. (2019) argue that the most successful patterns in energy saving are the one-hour pre- ventilating, it saves 5% more over the other patterns that could be due to shifting loads from the peak hours and save the overall consumption. The study was about scheduled ventilation in California house spaces which is not set up only on CO_2 concentration inside the spaces but also on people profiles. Referring to the literature review chapter section programable thermostat and strategies, the patterns can be implemented by using some advanced equipment, for example, people recognising monitors or programmed controllers that respond to the space working hours. The study focused on the level of ventilation to maintain indoor air quality (IAQ) and energy-saving by applying three patterns for the controller. These patterns are: pre-ventilating the spaces, minimise the level of the ventilation when the users are out of the spaces, and turn on the system one hour earlier.

While Papadopoulos et al. (2019) pointed out that just changing in thermostat setpoint can make a significant difference in energy saving. This type of building modifying can mostly save more than 20% of the overall consumption. However, saving is more in heating loads than cooling loads. Papadopoulos et al. (2019) examined the changing in the setpoint in various area in the US and found that energy using decreased in a stable climate to 60% more than in a warm climate.

On the other hand and relating to the literature review chapter section programmable thermostat, ASHRAE standard gives a deep explanation of types of programmed thermostat and strategies. It includes a detector and monitors together. One type is managed relating to space using time. This can be implemented by users themselves, or by applying patterns that adjust to space using time on/ off type. Besides, this thermostat can modify according to the day or even week space using time.

5.5 Winter Scenario.

As mentioned earlier in chapter 4 in the winter base case and the winter scenario, the thermostat set for 24 ^{o}C from 8:00 am to 16:00 in winter base case. The best method to improve the base case is to apply natural ventilation to the zones form 8:00 am to 11:00 am. The cooling system starts from 11:00 am to 16:30. As described in the previous chapter in the HVAC system section, office spaces are divided into three zones.

Despite the tempered glass partition in zone A and 4, all the internal doors are opened most of the time.

Through the IES VE Macroflu section, the type of the opening and the profile for the windows were set. The profile presents the opening time and condition as per controller formula.

The controller has the same Fuzzy principle, which works as (**If**/**Then**). The formula is, the windows open from 8:00 am to 11:00 am if the indoor temperature is greater from outside temperature and if the outdoor Relative Humidity is less or equal to 60%. So this controller has to achieve two conditions to let the window open, and it depends on the IES VE weather file for Sharjah city.

Figure 5.9 illustrates:

- Air temperature. (For the zone).
- Volume or the amount of air **In.** (For the zone).
- Volume or the amount of air **out**. (For the zone). Air exchange l/s inside the zone.

- Outside Dry bulb temperature. (From Sharjah weather file).
- Outside Relative Humidity (RH). (From Sharjah weather file).

Figure 5.9 is for zone 4 and for the window located on the northwest side. It shows the amount of airflow in /out for the northwest window. So the window is not opened until 9:02 am, the controller gives a signal to open the window because the Relative Humidity (RH) at that time is less or equal to 60% which is 59.8%. Also, the space temperature is 21.85 ^{o}C, and the outside dry bulb temperature is 19.11 ^{o}C. As before time 9:02 am, the RH is greater than 60% it reaches to more than 75%. However, the space temperature at the same time is greater than outside dry bulb temperature, but the window does not open until achieving the second condition. Thus, the air begins to flow in/out with the different amount depends on the wind direction at that time as shown in figure 5.9, as the graph of the airflows is not straight but changeable.

Figure 5.9 also shows the rising of the dry bulb temperature in the afternoon reaches to more than 27^{o}C as per Sharjah weather file, which needs the mechanical mode to assist the spaces with cooling and ventilation. The cooling system starts as per the thermostat schedule from 11:00 am to 16:30, the signal is given to close the window at 11:00 am as the controller formula is scheduled from 8:00 am to 11:00 am. (Check Appendix C).

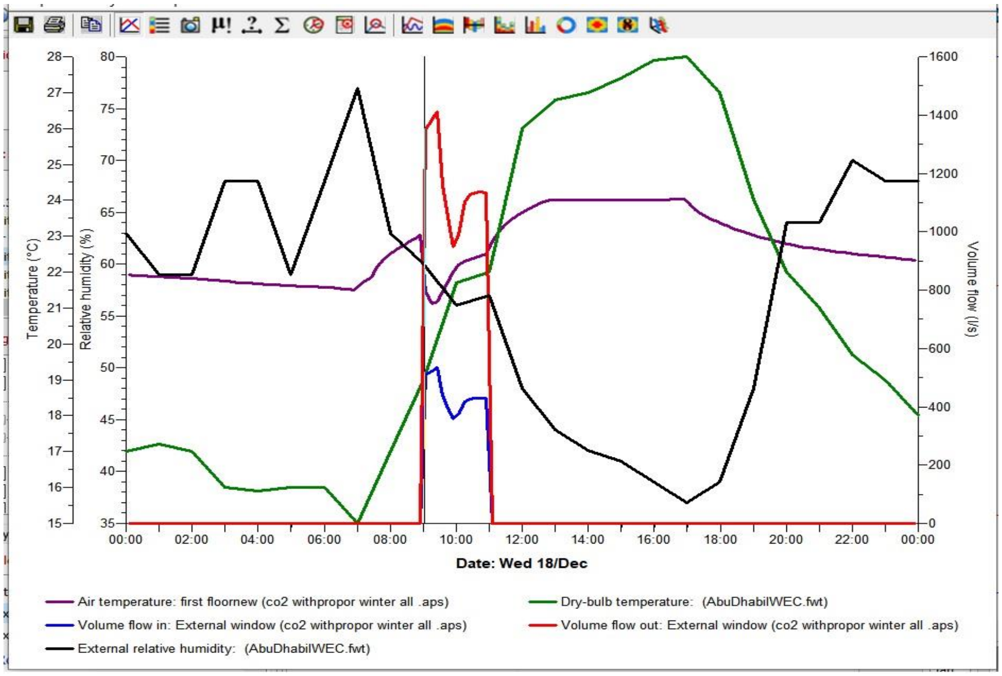


Chart Date/Time: Wed, 18/Dec 09:02.25

Variable Name	Line Colour	File Name	Location	Type	Value	Lock
Air temperature (°C)		co2 withpropor winter all .a	first floornew	Temperature (°C)	21.85	
Dry-bulb temperature (°C)		AbuDhabiIWEC.fwt	Model	Temperature (°C)	19.11	
Volume flow in (l/s)		co2 withpropor winter all .a	External win	Volume flow (l/s)	378.44	
Volume flow out (l/s)		co2 withpropor winter all .a	External win	Volume flow (l/s)	1002.16	
External relative humidity (%)		AbuDhabiIWEC.fwt	Model	Relative humidity (%)	59.8	

Figure 5.9 Winter scenario in 18thDec zone 4. (IES VE, Vista pro. /Room result.).

This scenario can achieve energy efficiency by 27.22% compared to the winter base case. Figure 5.10 shows the sensible cooling loads for winter months (December-February) for the winter scenario and winter base case.

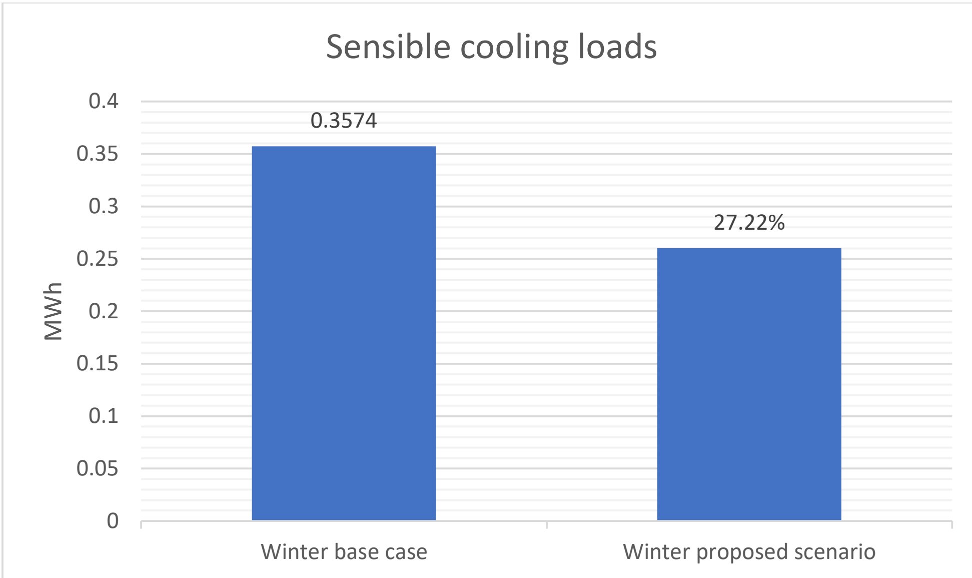


Figure 5.10 Cooling loads for winter scenario. (IES VE, Vista pro. /Room result.).

The idea of the winter scenario matches those observed in earlier studies. A study from Kim, Hong & Kim (2019) identified the elements that may manage the window controller pattern by a sensor. These elements mostly depend on IAQ like indoor air temperature and relative humidity. The window is not closed when one of these measurements override the certain setpoint.

Salcido, Raheem & Issa (2016) concluded from different studies about natural ventilation, that can be used with mechanical ventilation regarding the weather conditions, as mentioned in the literature review chapter in section mixed-mode ventilation. This type can conserve from the HVAC system around 40% if it involves open and close window pattern. And 75% if using two modes of ventilation, mechanical and natural. This type of ventilation system calls mixed-mode ventilation.

However, both of the above studies determined that naturally ventilated spaces that involve open and close windows is difficult to be controlled by the occupants. In other words, it is pointless to depend on the occupants inside the space to decide whether to open or close the window. This is one of the good reason behind using the controller.

5.6 Upgrading Summer and Winter Scenarios by Applying the CO_2 Controller.

It is apparent from the field measurements that the CO_2 levels vary in the office building during the day. Referring to the data collection section in chapter 4, it is important to note that the measurements were conducted under a specific environment. One of the issues that affect the readings is the number of the employee.

However, during the 6th of February measurements, Zone 5 had more than nine employees, and the thermostat was set on 24 ^{o}C. At 9:15 am in zone 5 the CO_2 was (979 ppm the exact reading), (855-1103 ppm with the tool accuracy), under 23.4^{o}C and 54.7% RH. At 2:30 pm, the CO_2 level was 716 ppm (826.8- 605.2 ppm with the tool accuracy). The reason behind the CO_2 fluctuation is the number of employees which is considered the main source of the CO_2. At 9:15 am, there were nine employees in the space, and at 2:30 pm three employees only. However, the FAHU keeps supplies outside air at the same level without response to the CO_2 level in the office zones. As a result, the number of workers is subjected to change with the same level of airflow. This type of system affects IAQ and system cooling efficiency.

Referring to the previous chapter section CO_2 controller for summer and winter scenarios, the CO_2 controller was applied to the office zones with a certain formula, which is the controller is on when the (CO_2 >=1000 ppm). The air supply will increase gradually to reduce the 1000ppm CO_2 concentration inside the office zones. The air supply stops for a while when the CO_2 level reaches a certain level below the control condition (1000 ppm). As previously mentioned and as per ASHRAE, this type of controller is Fuzzy, which means **if** the changeable amount (CO_2 level) reaches the setpoint (1000 ppm), **then** the fresh air will supply to reduce the CO_2 level inside the zones.

The controller is applied in scenario 3 which represent the operating system one and a half hour before office time. Also, the CO_2 controller applies to the winter scenario during the cooling time which is from 11:00 am to 16:30. The findings support the idea of how the CO_2 controller can work and what is its impact on system efficiency.

Figure 5.11 illustrates the CO_2 controller working method for Zone 4 scenario 3 at 12th of August as an example to understand the controller processing. It presents the correlation of CO_2 level and the amount of air supply which is inverse proportion; it means that when the air supplies to reach its average amount, the CO_2 peak graph goes down. So, for this study, The CO_2 level begins to rise gradually during the office time that is 7:30 am to reach to 1000 ppm or more, at that point the outside fresh air has supplied mechanically in a particular amount by AHU which determined the CO_2 level to be less than 1000 ppm as per the controller formula. After achieving the CO_2 level less than 1000 ppm, the air supply stopes for a specific time as per the acceleration in CO_2 level.

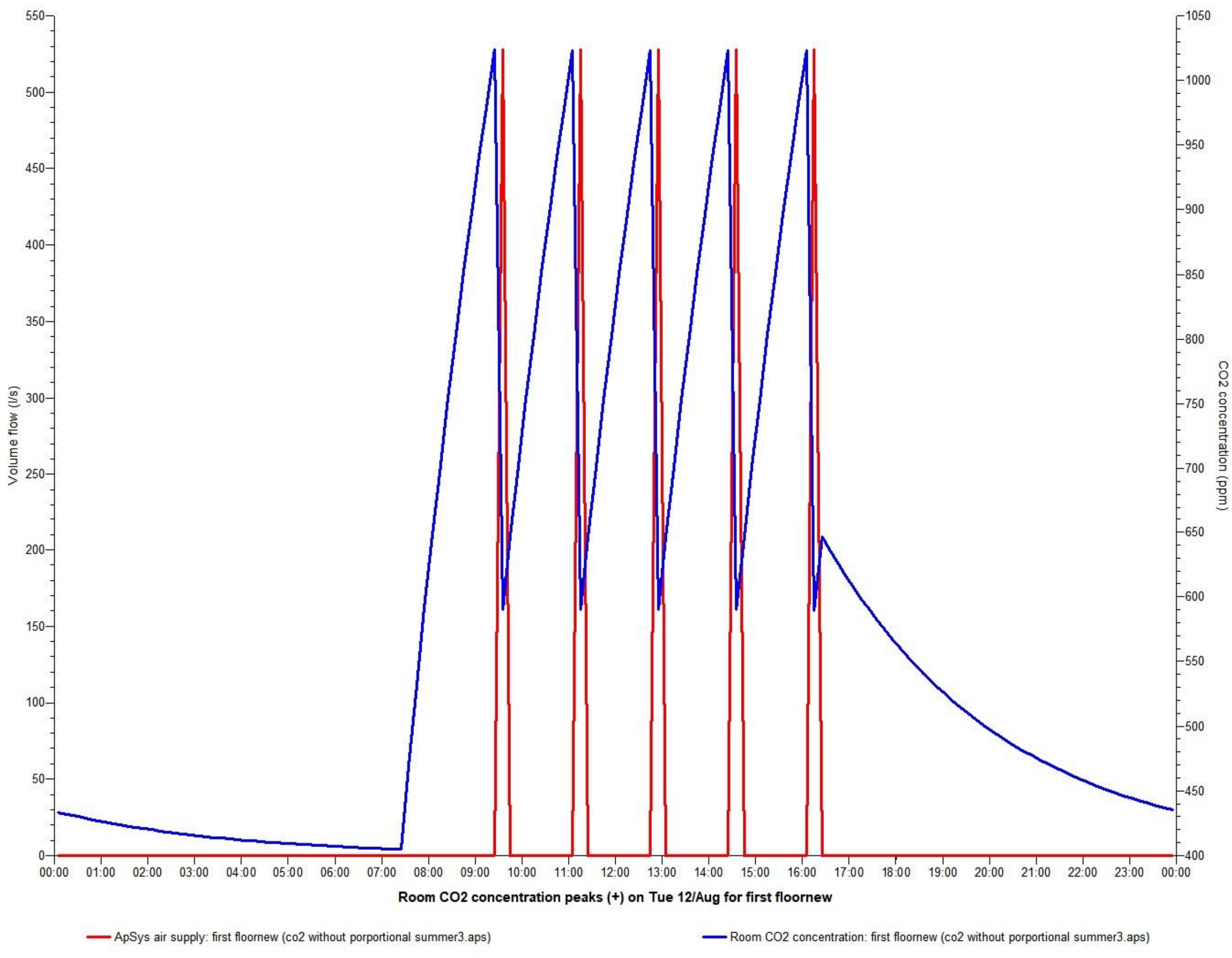


Figure 5.11 CO_2 controller pattern work for zone 4. (IES VE, Vista pro. /Room result.).

Table 5.7 supports the fact of figure 5.11. At 7:35 am the CO_2 level is 470 ppm, it significantly increases because of the number of the workers to reach 1024 ppm at 9:25 am. The airflow amount depends on the sensor signal to the AHU damper. For example, the airflow of 527.81 l/s can maintain less than 600 ppm. While the CO_2 level begins to increase to reach a certain level above 1000ppm, the air supply at that time is zero. In other words, the AHU stops from 9:45 am till 10:55 am. The same process repeats formally as in the IES VE simulation the number of the occupants or internal gain remains continuous at the same level. However, the correlation between airflow and CO_2 concentration depends on the number of workers inside the office zone. (Check Appendix B for zone A and 5).

So, the airflow of 527.81 l/s can maintain less than 600 ppm, when the maximum airflow is 1370 l/s for the office spaces. As with entering the amount of the airflow in the IES VE thermal template which works with office zone area to control the airflow and the minimum CO_2 level to reach, in this situation is less than 600 ppm. However, and as per one research paper (what is mentioned in the literature review chapter/ Mechanical Ventilation Strategies (CO_2 Controller)) by Chenari et al. (2017), another type of controller formula can be set to maintain also the minimum CO_2 level to reach, to let the AHU stopes. For example, setting a higher/lower level for the CO_2 control formula between 1000-500 ppm.

This view was supported by Pantazaras et al. (2018), who writes about the method beyond the CO_2 controller or demand control ventilation (DCV). It manages the level of the CO_2 regarding how many people inside the specific space. It means to regulate the amount of fresh air which has an essential influence on energy efficiency. While Merema et al. (2018) determined the threshold for the indoor CO_2 level as most of the CO_2 setpoint is equal or under 1000 ppm. Also explained the process of the DCV as when the CO_2 level rises to reach the setpoint the air supply boost to lower the CO_2 level this is during the occupancy time or working hours. In out of working hours, the air supply keeps down or stops. This process depends on a CO_2 monitor delivers a sign to the damper to let in the fresh air.

Table 5.7 CO_2 level and airflow amount in 12th of August /zone 4. (IES VE, Vista pro. /Room result.).

scenario3 /zone 4			
		ApSys air supply (l/s)	Room CO2 concentration (ppm)
Date	Time		
Tue, 12/Aug	7:15	0	405
	7:25	0	405
	7:35	0	470
	7:45	0	532
	7:55	0	591
	8:05	0	648
	8:15	0	702
	8:25	0	754
	8:35	0	804
	8:45	0	852
	8:55	0	898
	9:05	0	941
	9:15	0	984
	9:25	0	1024
	9:35	527.81	590
	9:45	0	647
	9:55	0	701
	10:05	0	753
	10:15	0	803
	10:25	0	851
	10:35	0	897
	10:45	0	941
	10:55	0	983
	11:05	0	1023
	11:15	527.81	590
	11:25	0	647
	11:35	0	701
	11:45	0	753
	11:55	0	803
	12:05	0	851

5.7 Overall Energy Efficiency for the Scenarios.

This section compares and discusses the simulation for full-year for the following scenarios: base case and Summer scenario 3 combined with the winter scenario, that means simulation for one year with & without CO_2 controller.

As explained in the base case scenario, the system loads obtained from sensible and latent heat. Many factors like building design convert to sensible heat, and many internal factors like the number of workers and their behaviour turn into latent heat which is responsible for humidity level. (Salameh et al. 2020).

After applying the CO_2 controller for the office spaces to gain more reduction in cooling loads and to enhance the IAQ, One finding is that there is no remarkable lowering in sensible cooling loads whereas there is a significant reduction in latent loads. Figure 5.12 illustrates the sensible cooling loads for the base case, summer scenario 3 with winter scenario (simulation for one year) with & without CO_2 controller. The proposed scenario can achieve 18.3844 MWh per year compared with the proposed scenario with the CO_2 controller which is 18.1978 MWh per year.

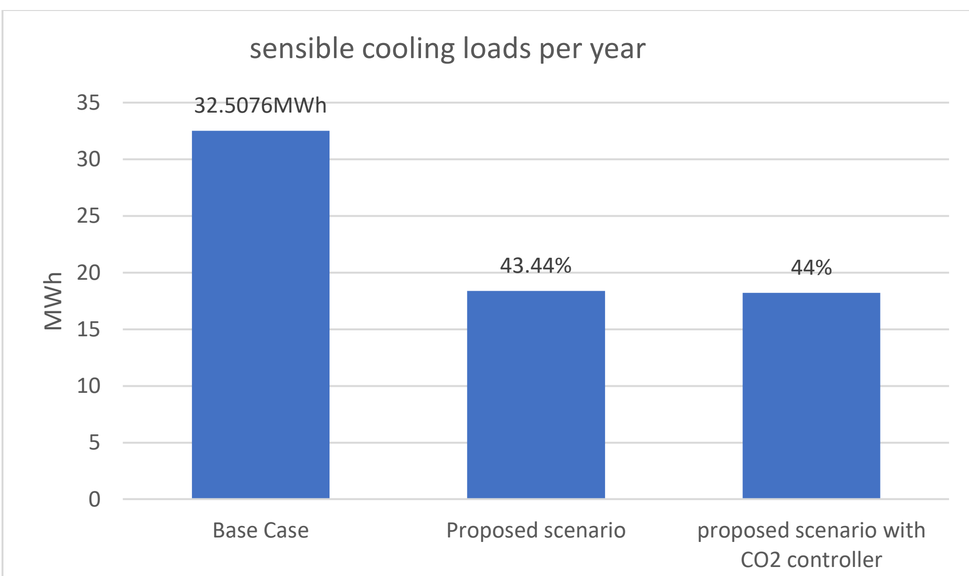


Figure 5.12 Sensible cooling loads for the scenarios per year.

However, figure 5.13 shows the latent and sensible loads for the three scenarios per year. The base case has a consumption of 198.1048 MWh compared with the proposed scenario which is 66.0943 MWh, and the reduction is around 66.63%. While the cooling load for the proposed scenario with the CO_2 controller is 24.7465 MWh for the whole year. Thus, it can obtain about 87.5% parallel with the base case.

Previous studies have reported a range of results due to the use of the CO_2 controller (DCV). One study by Merema et al. (2018) in Belgium, confirmed the effect of DCV not only on IAQ but also on the Fan consumption compared with Constant Air Volum (CAV) in spaces like offices and Auditorium in Universities. The Fan for Air handling unit can conserve energy between (40%- 75%) relating to the different months of the year. Another study by Ahmed, Kurnitski & Sormunen (2015) examined the Impact of DCV on energy consumption. DCV is vital to enhance overall building energy consumption besides the IAQ. It found that DCV can save 33- 41% in the HVAC system for the office spaces in Finland.

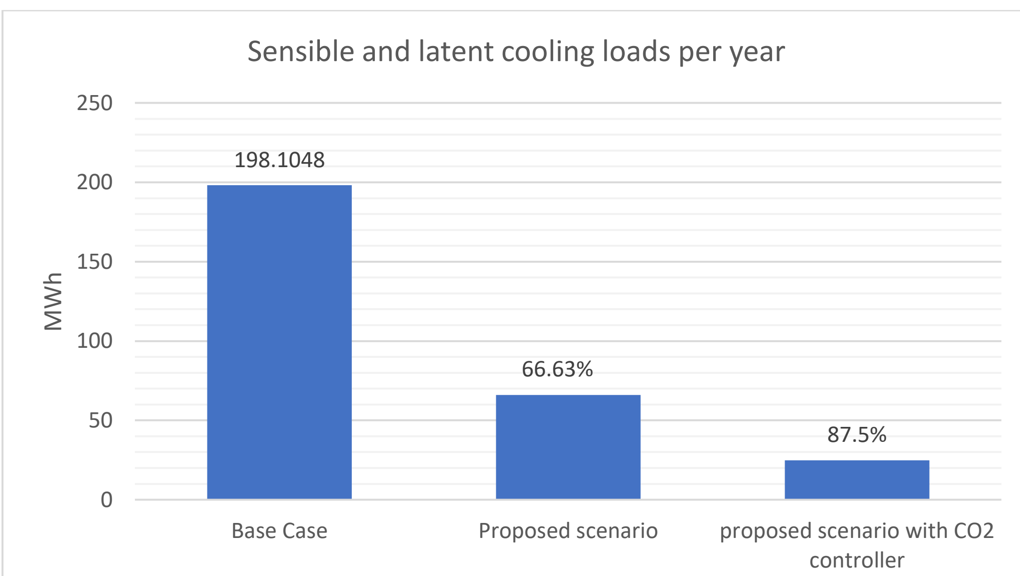
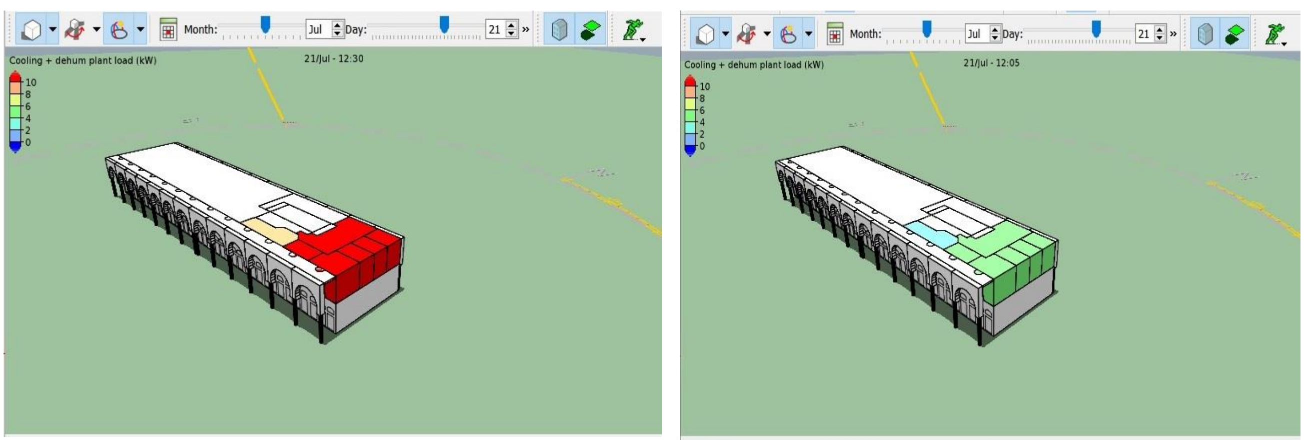


Figure 5.13 Overall cooling loads for the scenarios.

Overall and relating to the mentioned above, the latent loads depends on number of people and their behaviour. Each office zone has its specification, so the factor that affects the latent load is variable when dealing with number of people and their impact on the indoor humidity level. Another factor that affects the latent load is the outside relative humidity level in UAE which can reach to 100% in some days. The office cooling system has a FAHU which enables the outside tempered humid air to enter the office zones. Thus, the notable reduction occurs in latent loads when applying CO2 controller by using a specific formula. While the sensible heat effect by the passive design for the office building which is fixed value in this research. However, the reduction occurred in sensible loads when applying schedules to the thermostat under different scenarios.

Figure 5.14 present the sensible and latent loads for the office zones on 21st of July at 12:30 pm. The comparison is between the base case and the proposed scenario with the CO_2 controller. It is almost certain that the office zones in the base case scenario consume more energy than the proposed scenario.



Base Case

Proposed scenario

Figure 5.14 cooling loads for the base case and the proposed scenario.

Chapter 6 Conclusion

6.1 Research Overall Concept.

Relating to the previous studies and what it seems from the world concern, that energy usage in building sector from construction through operation or building life span is one of the many sources for increasing GHGs besides the pollutants that generate from construction. This research is concentrated on energy reduction in an office building in the UAE. The cooling system is responsible for the most electricity consumption of buildings in the warm climate like UAE compared with other systems, for example, lighting. This research is evaluated cooling strategies by programming the thermostats according to the building function and occupants behaviour which can be done by experiencing some scenarios for the office building and compared with the base case. These scenarios also can assist in understanding the peak hour loads and how to shift it. Then upgrading the optimal scenario by applying CO_2 controllers or DCV to achieve more energy reduction in the office building consumption and maintains the acceptable level of CO_2 which referring to the employees' health and productivity. Also, this research is focused on how CO_2 controller is working and the benefit of applying it in spaces characterised by fluctuating occupants number. Besides, the type of controller that is used in the winter scenario. It is noteworthy to mention that the evaluation for the scenarios was done under ASHRAE standard and AL SA`FAT Dubai.

This chapter is divided into three sections: first is about the concept of the scenarios; second is about the interesting findings; third is about future work.

6.2 Applying Different Scenarios.

- Using IES VE software to conduct the simulation under different scenarios by changing the input data, which is the thermostat setpoint and its profile.
- Study and collect the required data for the base case, which is an office building in Sharjah city and carry out the energy model by using IES VE software. The base case cooling system contains air cooled chiller, AHU and FCU. The thermostat keeps working with/without office time. However, in the summer

months the thermostat working under 21 ^{o}C continuously, in winter months the profile that the system works only within the working hours and under 24 ^{o}C for air temperature.

- Upon that the proposed scenarios divided into two summer scenarios and winter scenario to enhance the energy consumption for the building.
- The first scenario is by applying a program for the thermostat; which is the cooling system keeps working continuously same like the base case but by changing in the setpoint. Out of working hours, the setpoint is 25^{o}C and within the working hours is 21^{o}C. This system works under the precooling strategy.
- The second scenario is the cooling system profile works only in the working hours with the 21 ^{o}C for the air temperature.
- The third scenario also works under the precooling strategy but different than the first scenario. The precooling begin one and a half hour before and after the office time with setpoints begin from 25 ^{o}C to reach 21 ^{o}C in the office working hours.
- The fourth scenario also works continuously in/out working hours same like the first scenario but with different setpoints, 27 ^{o}C in out of working hours and 22 ^{o}C in office working hours. What mentioned above are scenarios for the summer months (March- November).
- For the winter months (December- February), the natural ventilation is introduced from 8:00 am to 11:00 am only the rest of the office hours continuous with the cooling system under setpoint 24 ^{o}C. However, previous studies identified that it is insufficient to depend on the employees to decide whether to open/close the window linked to out/inside weather condition. Accordingly, the controller is set under the specific formula in IES VE /Apache por. Which is window will open when the room temperature is more than outside dry bulb temperature, and the outside RH is lower than 60%. The controller will close the window at 11:00 am because the thermostat works at 11:00 am which provide cold air mechanically.
- Calculate the energy consumption per year for the optimal scenario from the summer proposals with winter scenario to compare it with the base case. Applying the CO_2 controller to the best scenario per year to maintain the indoor air quality with more reduction in energy consumption for the office building. The controller is work under

fuzzy logic which is if/then. So the formula is if the indoor CO2 level exceeds 1000ppm then the air supplies to minimise the level under 1000 ppm. In IES VE simulation the maximum airflow is used for a specific time to reduce the CO_2 level, then it stops until the CO_2 level reaches again to 1000 ppm. The CO_2 level depends on the number of people inside the office spaces, in the base case, the airflow keeps working whatever is the number of the employees, which is energy waste.

6.3 The Outcomes from the Simulation.

The first step toward evaluating and finding the optimal summer scenarios is by simulating the energy model in IES VE/ Apache dynamic simulation. The simulation is carried out for the summer months scenarios and the base case for sensible cooling loads. The results are for the three zones where the study is conducted. The comparison between the base case and the summer scenarios was carried out to find which scenario has a significant reduction in the sensible cooling loads. As the base case consumes 32.1503 MW/h. The lowering in percentage for Scenario 1 compared with the base case is 22.47% as this scenario works continuously out/within the working hours but with increase the setpoint to reach to 25 ^{o}C in out of working hours. Scenario 2 can achieve 41.25% compared with the base case, 43.63% reduction in scenario 3 and 29.2% in scenario 4. The second step to find the optimal scenario is by achieving the goal of load shifting from the peak hour. Scenario 3 can achieve a significant reduction in sensible cooling loads per year; besides, this scenario can shift the load from the first hour of office time by using the one and half hour precooling strategy compared with the other summer scenarios. The base case which implements a notable load shifting but the main problem is the overall electricity consumption as the thermostat set for 21 ^{o}C continuously without adapting the precooling mode which causes this significant consumption. The same procedure is used for the winter scenario which can achieve reduction reaches to 27.22% compared with the winter base case. Looking for the electricity consumption per year, as the base case 32.5076 MW/h, and by combined the optimal summer scenario which is scenario 3 with winter scenario the sensible cooling loads 43.44% reduction compared with the base case. The CO2 controller is applied to the scenario to achieve more reduction in energy. The controller works to regulate the outside airflow through AHU as per employees' number and controller formula.

The simulation shows that there is no remarkable decrease in sensible cooling loads per year for the base case, the proposed scenario with/without the CO_2 controller. However, a significant reduction appears in latent loads. The final comparison is carried out between the base case, the proposed scenario with/without the CO_2 controller for overall cooling loads (sensible/ latent loads) per year. As the proposed scenario with the CO_2 controller achieves 87.5% compared with the base case.

It seems possible that these results are due to the improvement in some building strategies that can achieve a significant reduction. In the base case, the thermostat setpoint and its pattern with the constant airflow consume more energy in sensible and latent loads. As the system operates for all Summer months continuously. By managing the air temperature setpoint under a specific schedule and maintain the airflow according to the indoor CO_2 concentration, can implement a significant reduction in the HVAC system energy consumption. The energy model simulation in IES VE confirms these strategies in this research. The present study makes several noteworthy contributions to the idea of the precooling plans and recognised the exact reduction in sensible and latent loads for overall building energy when using CO_2 controller or DCV. Also, this research will serve as a base for using the programmable thermostats, CO_2 controller, and type of controller in the winter scenario that manage the time and condition of the opening window. Both controllers are working under the fuzzy method, which depends on the already set formula.

6.4 Recommendation for Future Studies.

This research has thrown up many questions in need of future investigation, for example:

- Experience different airflow that can CO_2 controller works with, as per ASHRAE 90.1 the airflow should not be less than 600 L/s that let the CO2 controller or DCV works appropriately according to the zone area and the maximum number of the occupants.
- Conduct more scenarios relating to the passive strategies with the same strategies in this research. As mentioned in the literature review chapter/Cooling System consumption in the UAE and the peak load section that thermal mass has a significant impact in energy reduction combined with the active strategies. The thermal mass design with precooling mode, which can be implemented through programmable thermostat with a different set point according to the space function, can achieve notable strategies in energy reduction. Thermal mass can be tested by conducting a simulation in IES VE and changing the properties of the building materials in the construction template.
- Extend the simulation in precooling strategies by measuring the indoor surface temperature. Create scenarios that may work under passive strategies through changing the finishes materials and find the temperature for each type. This strategy may assist in identifying if the types of finishing materials (e.g. wooden cladding, fabric, painting) have a significant impact on the precooling mode by reducing the spaces indoor temperature
- Carry out the simulation in the same building with the same strategies but different spaces (e.g. corridor and conference room). Corridors have a high level of infiltration and conference room have a notable fluctuating in the number of occupants. Also, simulation can be conducted in different stories to identify if there is any difference in energy consumption.
- Implement active strategies in a different climate (e.g. cold weather), which be under heating loads and identify the optimal scenario for the office building to reduce energy consumption and manage occupants thermal comfort.
- Carry out this research to another track which is dealing with the source of the building electricity. This design may offer to provide electricity on-site, for example,

photovoltaic PV, or can redesign the office building with solar panels to get into building-integrated PV (BIPV).

- In mixed-mode ventilation, most of the research papers examined or suggested the software/ algorithm or the type of the controller of the window opening without studying the mechanism of the window opening. And the current research suggests the type of controller and formula. One study by Salcido, Raheem & Issa (2016), suggested using a platform signal to inform the employees to open the window as per the monitor formula. This may be a valuable subject to look at for improving the mixed-mode ventilation strategies.

6.5 Suggestion for Future Work.

The result of this study supports the idea that, When designing an office building, it is vital to understand the impact of active strategies on the energy-saving integrated with passive design to achieve more energy-saving and indoor environmental quality. It has been proposed that programmable thermostats have a significant effect on energy saving in the office building, which is complicated relating to its fluctuating in the internal loads. Manage the indoor temperature through programming the thermostats according to the daily routine for each space in the office building may reduce the cooling system consumption.

However, achieve thermal comfort for the employees is not enough for an optimal scenario, maintain the CO_2 level in spaces characterized by fluctuating in employees number, can obtain more energy-saving and enhance the indoor air quality. CO_2 controllers may be applied with a specific formula relating to the HVAC system and the amount of the airflow as per ASHRAE.

Besides, introduce the idea of using and managing the natural ventilation in the office areas which may assist in energy-saving and promote the indoor air quality even in the warm climate like UAE.

As it has been recognized that even in winter months, people in the UAE keep using the cooling system and ignore the reduction in outside dry bulb temperature. Engineering working under an integrated process to design such complicated buildings and by understanding the employees' behaviour is an essential way to implement a successful life span for the building. Overall, this research extends our knowledge of merging and using the technologies in the building system and several active strategies to enhance building performance.

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Appendix A Cooling Loads (peak hours) for the Summer Scenarios.

Table 1A: office zones scenarios.

Scenarios	Summer months base Case	Winter months base Case	Scenario 1	Scenario 2	Scenario 3	Scenarios 4	winter Scenario	Upgrade the optimal scenario
Cooling system profile	24/7	7:30 am to 16:30 working hours only	24/7	7:00 am to 17:00	6:00 am to 18:00	24/7	working hours only	Co2 controller
Thermostat set point for working hours.	21 ^{o}C	24 ^{o}C	21 ^{o}C	21 ^{o}C	21 ^{o}C	22 ^{o}C	8:00 am to 11:00 as per gt(ta,to,2) &(rho<=60)	As per CO_2 >=1000ppm
Thermostat set point for outworking hours	21 ^{o}C	AC off	25^{o}C	AC off	25 -23^{o}C	27 ^{o}C	AC off	As per the scenarios

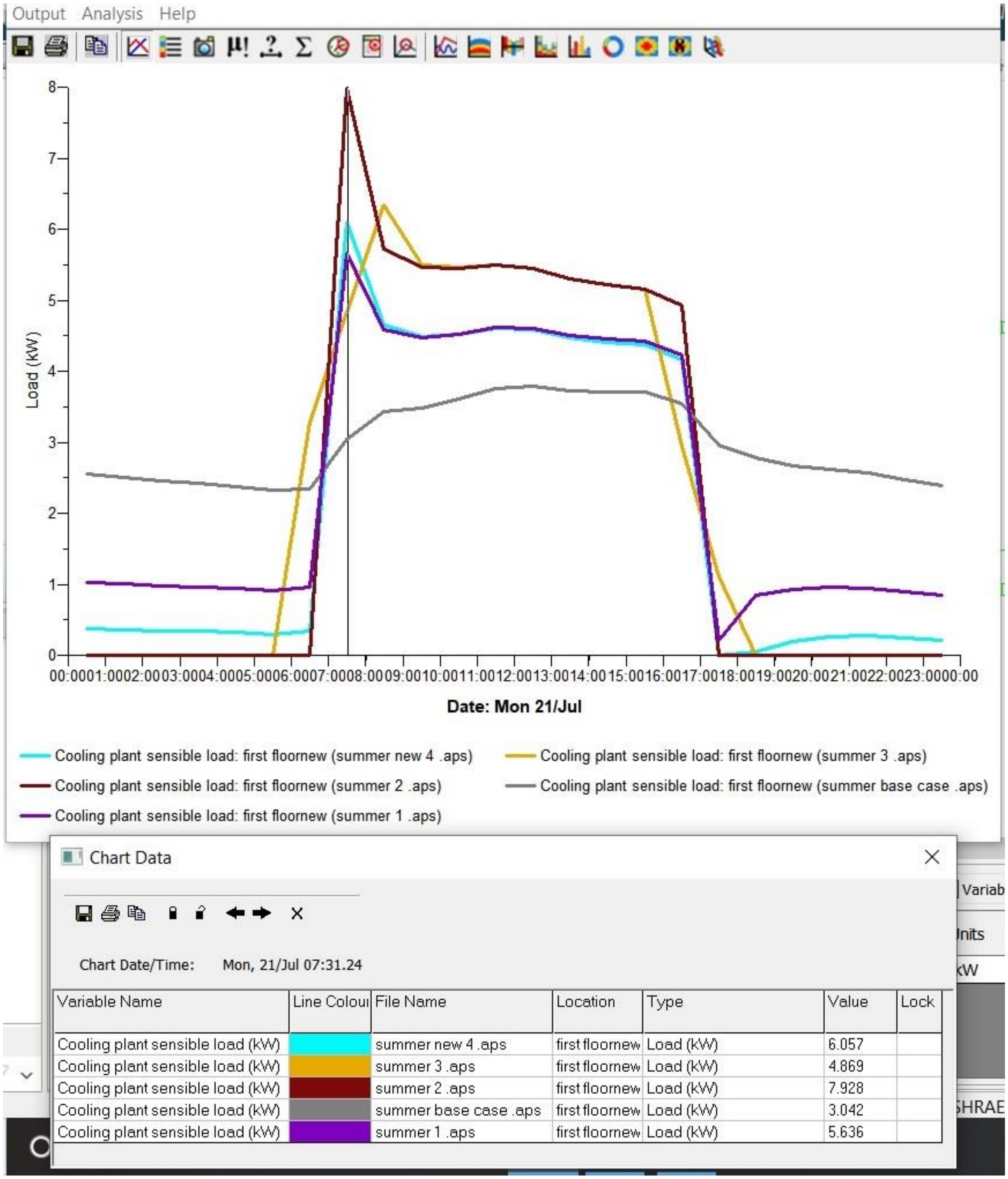

Figure 1A: Cooling loads and the peak hours load for zone A.

Table 2A: Cooling loads and peak hour for zone A.

Cooling plant sensible load (kW) /zone A						
Date	Time	summer scenario 4	summer scenario 3	summer scenario 2	summer base case	Summer scenario 1
Mon, 21/Jul	0:30	0.381	0	0	2.558	1.027
	1:30	0.362	0	0	2.504	1.001
	2:30	0.346	0	0	2.455	0.978
	3:30	0.341	0	0	2.42	0.967
	4:30	0.325	0	0	2.376	0.945
	5:30	0.299	0	0	2.321	0.913
	6:30	0.349	3.284	0	2.343	0.957
	7:30	6.09	4.834	7.98	3.033	5.661
	8:30	4.647	6.335	5.723	3.426	4.588
	9:30	4.481	5.504	5.464	3.479	4.466
	10:30	4.518	5.459	5.453	3.606	4.52
	11:30	4.6	5.498	5.497	3.75	4.614
	12:30	4.581	5.447	5.448	3.787	4.607
	13:30	4.464	5.303	5.304	3.722	4.503
	14:30	4.401	5.213	5.214	3.703	4.449
	15:30	4.372	5.157	5.158	3.715	4.428
	16:30	4.168	2.947	4.93	3.551	4.232
	17:30	0	1.105	0	2.961	0.206
	18:30	0.046	0	0	2.778	0.839
	19:30	0.201	0	0	2.668	0.925
	20:30	0.261	0	0	2.621	0.952
	21:30	0.269	0	0	2.564	0.943
	22:30	0.239	0	0	2.479	0.899
	23:30	0.205	0	0	2.392	0.853

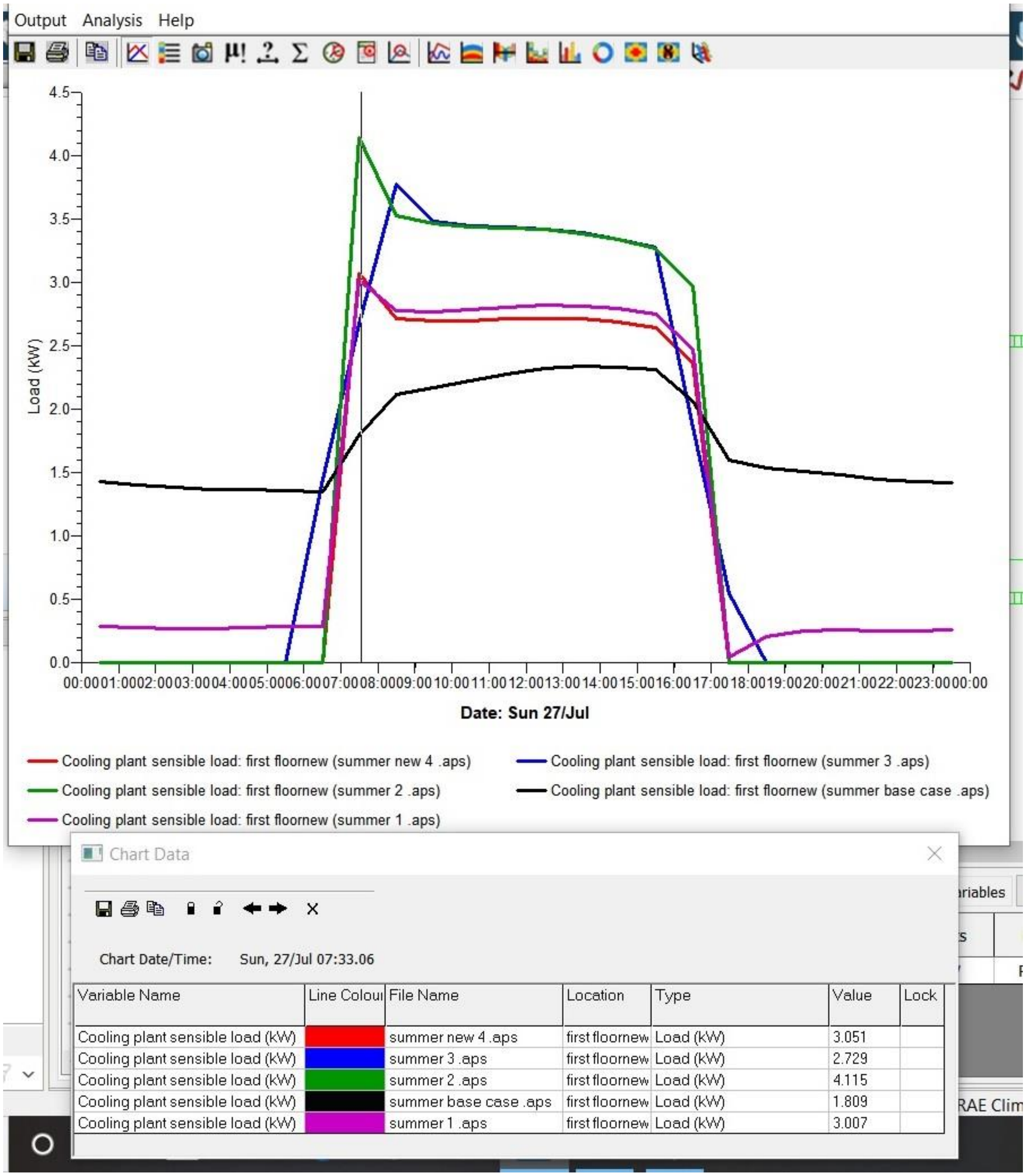

Figure 2A: Cooling loads and the peak hours load for zone 5

Table 3A: Cooling loads and peak hour for zone 5

		Cooling plant sensible load (kW) /zone 5				
Date	Time	Summer scenario 4	summer scenario 3	Summer scenario 2	Summer base case	Summer scenario 1
Sun, 27/Jul	0:30	0	0	0	1.43	0.285
	1:30	0	0	0	1.404	0.278
	2:30	0	0	0	1.381	0.269
	3:30	0	0	0	1.365	0.265
	4:30	0	0	0	1.365	0.277
	5:30	0	0	0	1.357	0.282
	6:30	0	1.447	0	1.344	0.282
	7:30	3.069	2.672	4.147	1.792	3.02
	8:30	2.715	3.781	3.526	2.115	2.775
	9:30	2.693	3.482	3.463	2.172	2.767
	10:30	2.699	3.45	3.439	2.225	2.782
	11:30	2.711	3.441	3.432	2.281	2.807
	12:30	2.718	3.424	3.416	2.319	2.819
	13:30	2.714	3.393	3.385	2.336	2.814
	14:30	2.69	3.344	3.337	2.334	2.791
	15:30	2.644	3.278	3.272	2.313	2.75
	16:30	2.367	1.856	2.976	2.059	2.477
	17:30	0	0.545	0	1.597	0.047
	18:30	0	0	0	1.539	0.209
	19:30	0	0	0	1.511	0.248
	20:30	0	0	0	1.482	0.255
	21:30	0	0	0	1.451	0.251
	22:30	0	0	0	1.427	0.249
	23:30	0	0	0	1.42	0.259

Appendix B The CO_2 Controller

Table: 1B CO_2 controller for zone 5

The CO_2 Controller Zone 5			
Date	Time	ApSys air supply (l/s)	Room CO2 concentration (ppm)
Tue, 12/Aug			
	7:35	0	570
	7:45	0	725
	7:55	0	874
	8:05	0	1016
	8:15	246.51	616
	8:25	0	768
	8:35	0	914
	8:45	0	1054
	8:55	246.51	626
	9:05	0	778
	9:15	0	923
	9:25	0	1063
	9:35	246.51	629
	9:45	0	780
	9:55	0	926
	10:05	0	1065
	10:15	246.51	630
	10:25	0	781
	10:35	0	926
	10:45	0	1065
	10:55	246.51	630
	11:05	0	781
	11:15	0	927

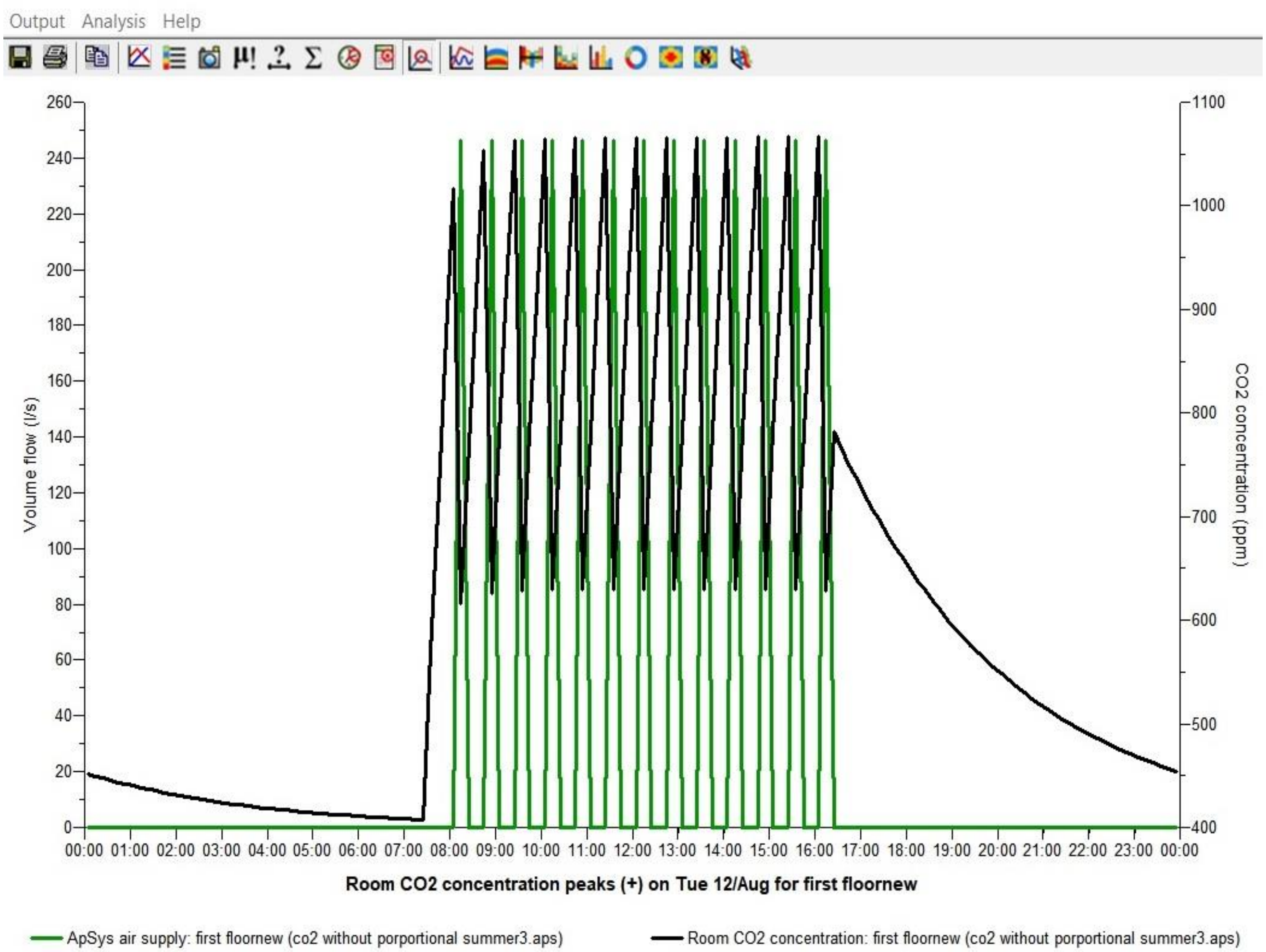

Figure: 1B CO_2 controller for zone 5

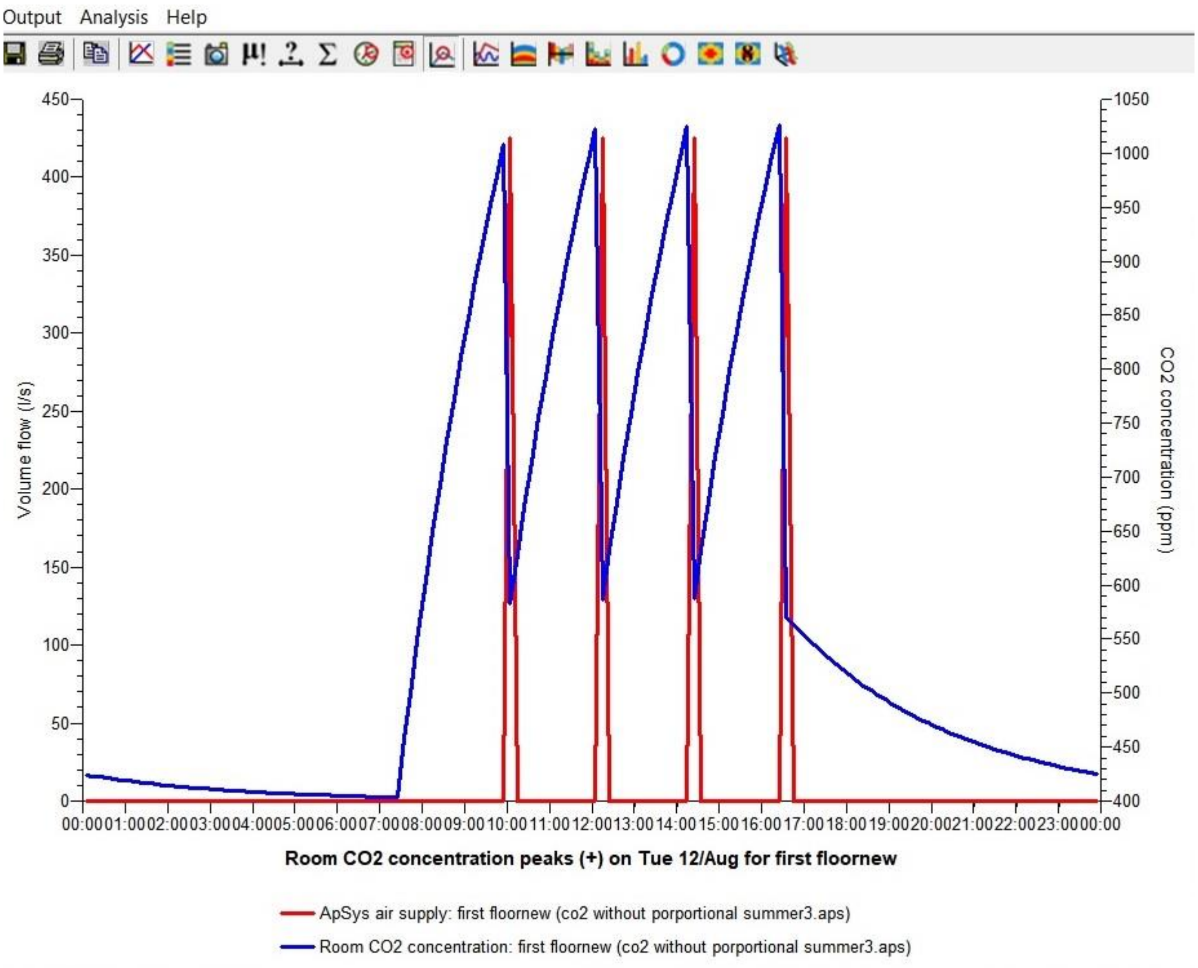

Figure: 2B CO_2 controller for zone A

Table: 2B CO_2 controller for zone A

The CO_2 Controller Zone A			
Date	Time	ApSys air supply (l/s)	Room CO2 concentration (ppm)
Tue, 12/Aug	9:25	0	916
	9:35	0	948
	9:45	0	978
	9:55	0	1008
	10:05	425.48	583
	10:15	0	629
	10:25	0	672
	10:35	0	714
	10:45	0	755
	10:55	0	793
	11:05	0	830
	11:15	0	866
	11:25	0	900
	11:35	0	933
	11:45	0	964
	11:55	0	994
	12:05	0	1023
	12:15	425.48	587
	12:25	0	632
	12:35	0	676
	12:45	0	718
	12:55	0	758

Appendix C Winter Scenario Macroflo

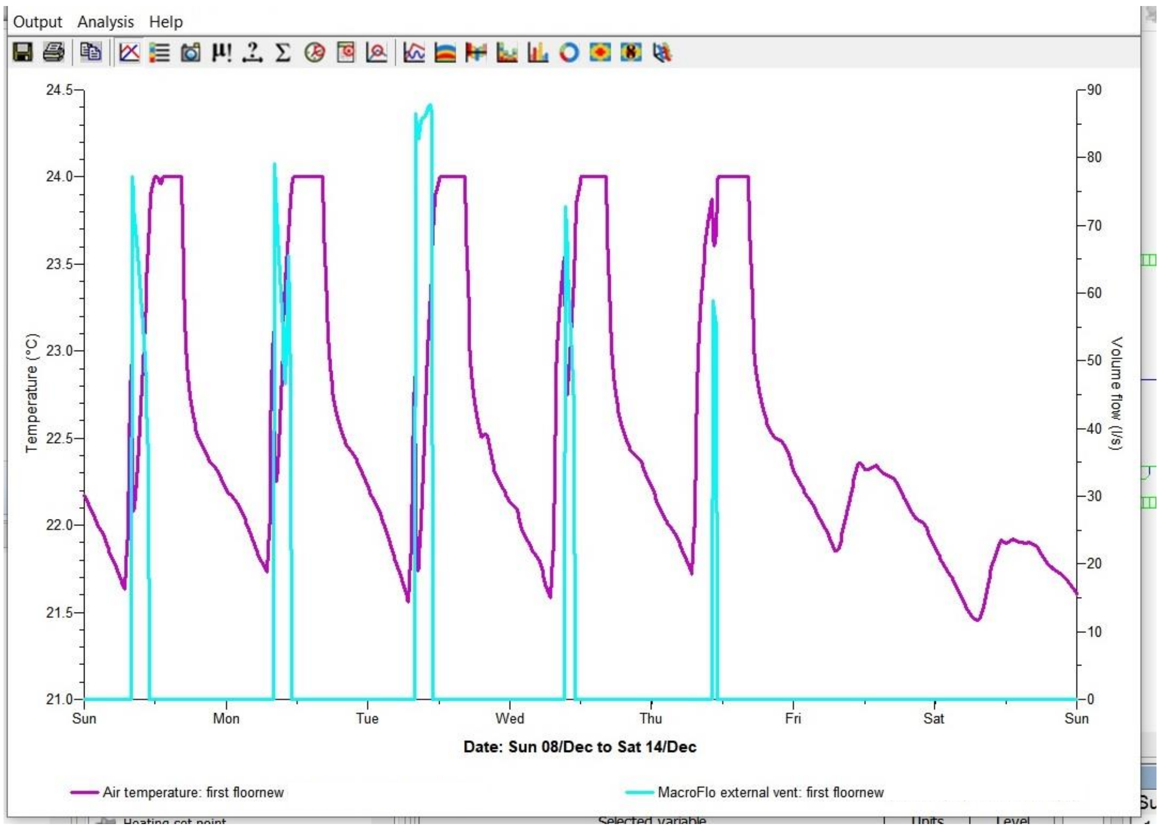

Figure 1C: Winter scenario air exchange and air temperature in macroflo/ IES VE for zone 5 as an example through the week.

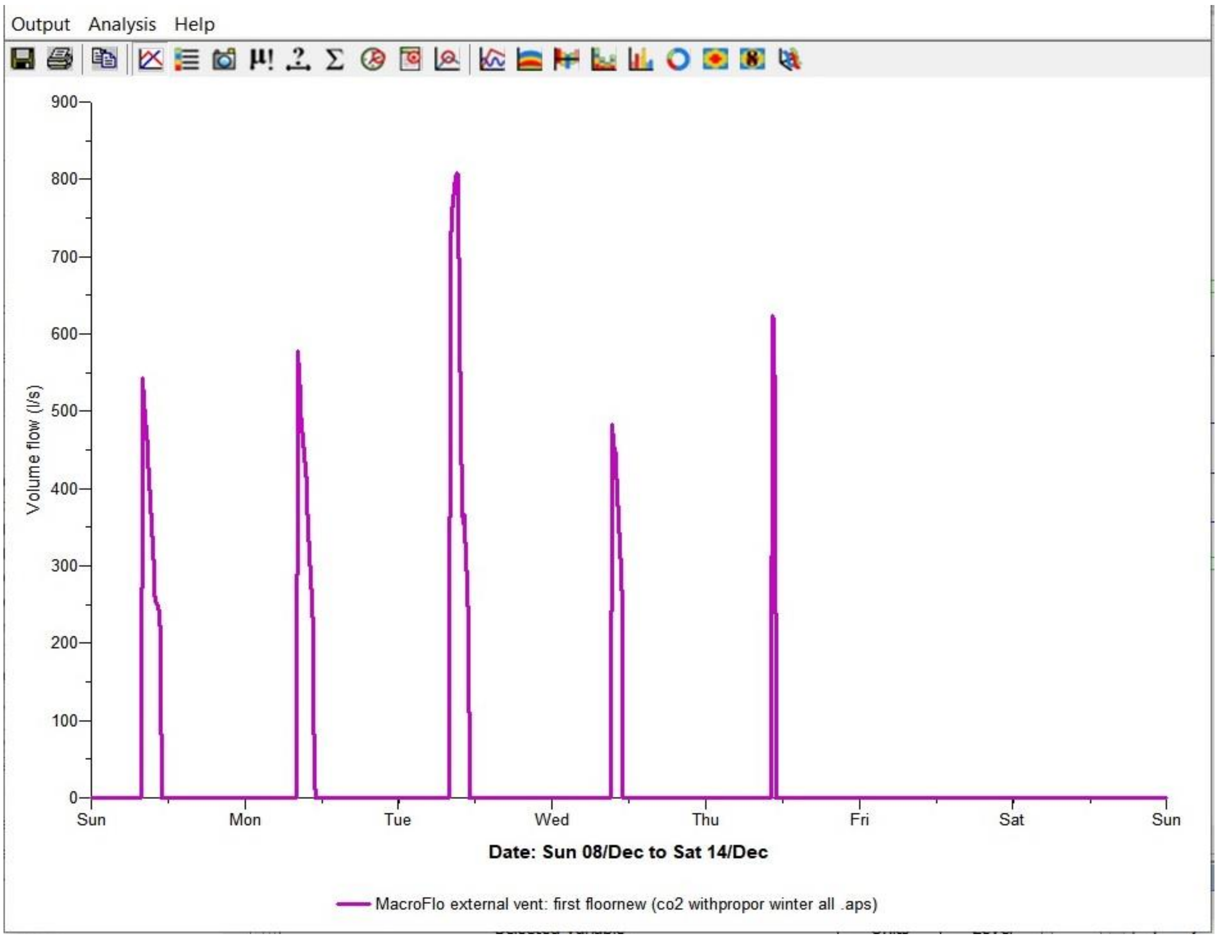

Figure 2C: Air exchange in macroflo/ IES VE for zone 4 through the week as an example.

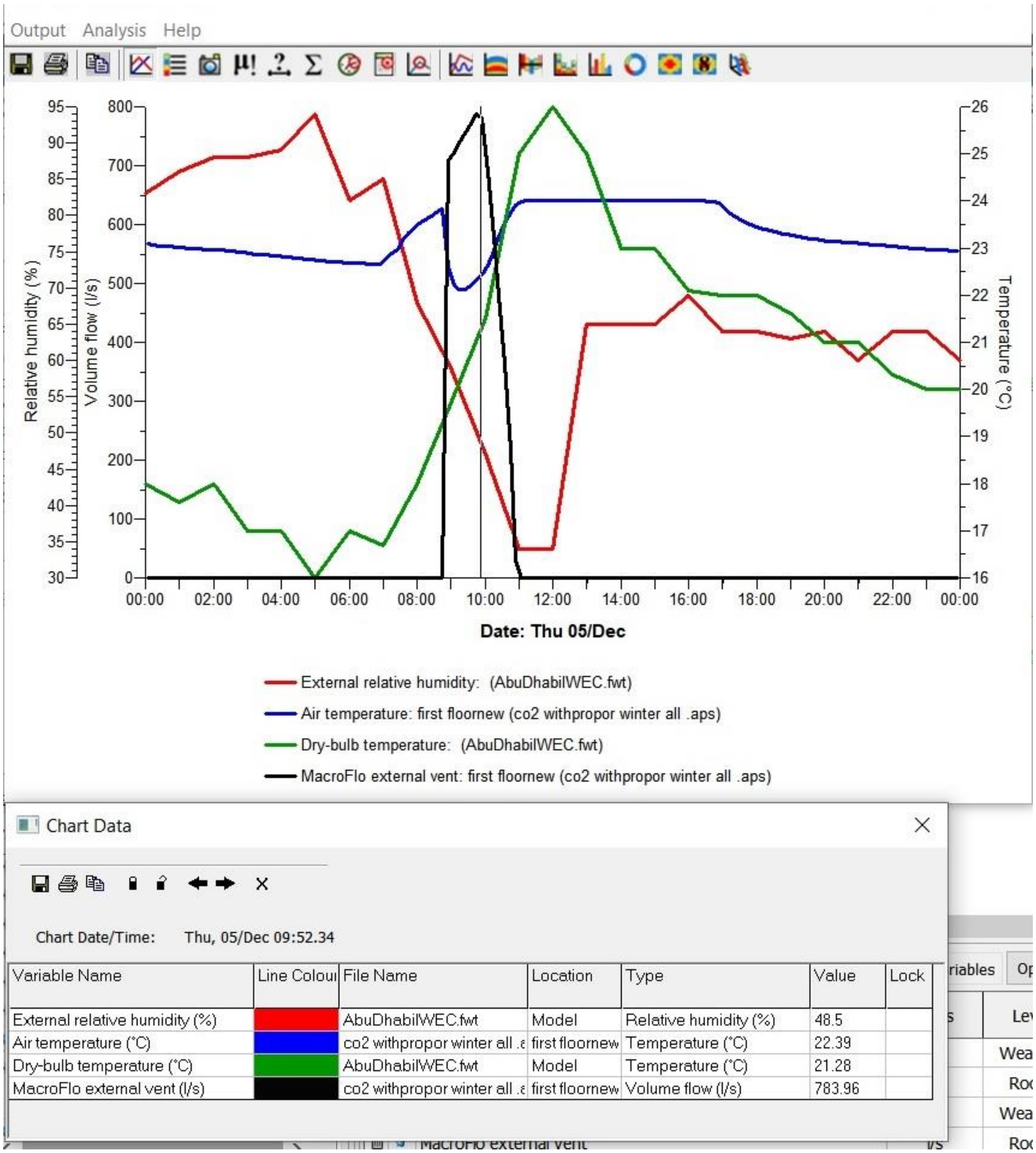

Figure 3C: The winter controller working process/ zone A / the 5th of December.