Department of Mechanical and Aerospace Engineering

Opportunity for Mechanical Ventilation Heat Recovery System in Hotel Sector

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ABSTRACT

Consumption of electrical energy and CO_2 emission was high in hotel sector. Therefore to curb power consumption and to improve the indoor comfort a new approach had proposed by re-use of warm air or moist exist in the hotel with the application of Mechanical Ventilation Heat Recovery hotel (MVHR) system and energy required for operation was investigated in this report.

Literature review on low carbon and energy conservation measures adopted in hotels across various country was examined. Later cause and effects of indoor air quality issues affecting the building environment and human health was reviewed with the recommendations to overcome the problems. Consequently different ventilation strategies and distinct reason for selecting MVHR system was examined. Beside methodology and steps implemented to model a hotel and plant system was explained

Model a storey hotel (ground floor and first floor) with their actual construction materials, optical properties and employing an air handling unit incorporated with heating coil and cooling coil was simulated in Building Energy Management Tool (ESP-r). Spread sheet calculation are carried out for modelling the duct system.

A model without plant system was primarily simulated at summer and winter seasons to examine the zones- indoor environment comfort, DB temperature, wind speed & direction, relative humidity and power and hours required for cooling and heating purposes. Further, analysis is carried out with employing plant system and result obtained is compared with the previous result. Besides the effective utilization of electric power is determined by calculating the power factor with the findings of real and reactive power consumption in kWh over each month. In addition, post occupancy evaluation of the building is carried out and compared with energy bench mark to find the standard of the building.

Result analysis and discussion highlight the improvement obtained in indoor comfort of the zone with the correspondence change in dB temperature and relative humidity level. Furthermore, recommendation to improve the efficiency of the plant as well as to reduce the hotel power consumption was discussed.

MVHR system appears to be the best way to provide both heating and cooling to the zones of hotel to improve the human comfort by the way of utilizing the heat or moist air. On adopting this methodology would minimizes the power consumption as well as carbon emission.

Acknowledgements

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NOMENCLATURE

Zone	**Description**
RT	Restaurant
KN	Kitchen
SCN	Staff canteen
PR	Plant room
OE	Office
MR1	Meeting room 1
MR2	Meeting room 2
SE	Store
US	Up stairs
SS	Stairs
LY	Lobby
PW1	Pathway 1
PW2	Pathway 2
SR	Store room
B1	Bedroom 1
B2	Bedroom 2
B3	Bedroom 3
B4	Bedroom 4
B5	Bedroom 5
B6	Bedroom 6
B7	Bedroom 7
B8	Bedroom 7
M1	Master room 1
M2	Master room 2
M3	Master room 3
M4	Master room 4
SB1	Small bedroom 1
SB2	Small bedroom 2

1 INTRODUCTION

Globally, hotel sector is one of the fast growing industry providing jobs for over 200 million people and leads to a status of greatest employee recruiter. People generally prefer hotel for various reasons like leisure, business and entertainment. Among this, it is mainly connected to tourism and flow rate is high as well as holds the main revenue contribution. In many countries it plays as one of the most important economy flow sector. Throughout the world there are over 2155 hotel groups with 61076 hotels which encompasses 8119731 rooms [1]. Hence to attract the tourist, huge amount of money is invested in amenities, entertainment and hotel environment comfort.

Hotels are classified in to one star, two star, three star, four star and five star hotels. This assortments are made in terms of building infrastructure, room space and comfort, high-tech equipment in each room, swimming pool and gym, furniture's and lighting facilities [2]. The hotel which incorporates the above facilities to increase the customer inflow, consumes large amount of resources like water, food, electricity and fuel. This resource utilization will differ substantially from various hotel types and influenced by size, class, number of rooms, locations and climate zone. Besides consumption of the above resources, this results in potential emissions like carbon dioxide, nitrous oxide, hydro fluorocarbons, etc. released to air, water and land. The potential emissions from this sector causes furthermore increase in environmental threat like global warming, acid rain etc. Therefore to reduce this negative effect on the environment as well as to reduce the energy consumption and cost, use of low carbon technologies and efficient devices have emerged in each and every sector.

Low carbon technologies have a crucial role to play imminently in a green economy. This promising technology have a tendency to reduce the carbon foot print at every stage of process from low carbon energy generation, through storage and transmission, to end user efficiency. This technology is associated with low carbon building, low carbon fuel standard and low carbon power. Low carbon buildings are designed and constructed in a way to decrease greenhouse gas emission throughout its life time. Buildings are responsible for 38% of CO2 emission (20% residential, 18% commercial) [3]. CO2 emissions associated with building operations are mainly from:

- Electricity consumption
- On-site waste water treatment
- On-site solid wastes treatment

An energy efficiency measure accomplished to curb greenhouse gas emission and to save the energy bills are achieved through the architectural building design such as natural ventilation, open space for solar absorption, etc. Further many technologies like cavity wall and loft insulation, double glazing, triple glazing and energy efficiency machines like CHP, MVHR, HVAC and heat pumps are emerged to reduce carbon emissions, power consumption, indoor air contaminants, etc. Coupling MVHR with heat pumps reduces the electricity consumption but it’s is expensive [4].

Ventilation serves a major part in indoor air quality. There is a standard value allocated for air exchange and when it deviates the standard value then discomfort and indoor air quality issues are created inside the building. According to the National Institute for Occupational Safety and Health’s (NIOSH) finding, “in 52% of our investigations, the building ventilation has been inadequate”. This inadequate ventilation cause serious health problems and discomfort [5].

Recent surveys show that the UK is one of the countries with the highest prevalence of respiratory symptoms and asthma worldwide, both for children and adults (Janson C. et al., 2001; ISAAC Steering Committee, 1998). A number of studies indicate that between the mid-1960s and the mid-1990s there was an increase in asthma prevalence in the UK of approximately 5% per year (Devereux G. et al., 2003). This is due to indoor dust mites and moulds form at higher indoor moisture level. This could be avoided by installing dehumidifiers or ventilation system [5].

The project benefited from access to a Holiday inn hotel at theatreland in Glasgow granted through Chardon Hotel Management Ltd. The theme of the dissertation is to improve the indoor environment comfort of the guest rooms by the use of exhausted heat or warm air from the hotel. For this purpose MVHR system is installed in the building.

2 LITERATURE REVIEW ON LOW CARBON TECHNOLOGIES AT HOTEL SECTOR IN VARIOUS COUNTRIES

In worldwide commercial sector, hotel industry is the major consumer of power and water and high producer of waste. Hence the awareness among the hoteliers have emerged regarding the social and environmental impacts and drive them towards the sustainability through their operation and development. To achieve sustainability hoteliers are greatly aims on to diminish the impact on the environment as well as to improve their operational efficiency in three major sectors

- Energy
- Water and
- Waste

ENERGY

The cost of energy consumption in hotel accounts for 3-6% of total operating cost, which holds a very small section of complete turnover. The following Table-1 represents the categorization of three different zones serving for various purposes [2].

ZONES	SUB-CATEGORY	ENERGY TYPE
Guest room area	• Bedrooms • Bathrooms • Toilets	Low energy load region (lighting, smaller appliances & ventilation)
Public area	• Reception halls • Bars • Restaurants • Conference hall • Swimming pool • Gym	High internal load region (Occupants, equipment, Ventilation, cooling, heating & Lighting)
Service area	• Kitchen • Store rooms • Laundry services • Machine rooms	Energy accelerating region (24hr occupancy, Ventilation, Cooling & heating)

Table 1: Representation of zones, subcategories and energy type [2].

The energy flow rate in the above regions vary from time to time and it has to be handled in an appropriate way. Monitoring and record keeping of the energy flows in each region by an advance equipment is possible but it is costlier and complicate to implement it. By installing energy efficient devices for lighting, heating and cooling systems hoteliers can diminish the cost of energy consumption and recycle the waste effectively. The following hotels represents the practices executed by the hotelier in some countries across the world.

Resource conservation measures taken by hotels in the countries:

2.1 UNITED KINGDOM (UK)

The Great Hallingbury Manor:

The hotel has imposed various energy saving technologies during construction as well as in the retrofit. The energy conservation technology equipped by the hotel are the following:

- Insulation and double glazed windows are installed to reduce the thermal losses in the building.
- Ground source heat pump is installed to extract the natural heat from the earth surface to heat the water which is supplied to hotel and restaurant.
- Nordic converters are used to provide cooling and heating for the offices and conference room.
- The portion of hotel electricity is provided by a bio-diesel generator, which takes recycled cooking oil as a fuel.
- Waste food is recycled using food waste disposer device in terms of high grade soil fertilizer for vegetables, fruits, herbs, etc. [6].

The Guoman Hotel:

Light Emitting Diode (LED) is equipped as a basic standard in the building, specially designed motion sensors have been installed in conference rooms and energy efficient air conditioning units are installed to conserve energy usage. Moreover water usage is effectively reduced by installing tap restrictors and dual flush [7].

Manor House Hotel:

Hotel is equipped with LED and solar panels. Solar panel is used to heat the water and supplied to sanitary service. The hotels have installed toilets that use less water. Manor House also instituted a policy of using its washer only when it has a full load ready to be cleaned. It uses low-energy light bulbs, and it heats its water with solar panels [8].

Swinton Park:

The hotel provides heat and hot water is supplied by a wood-chip boiler. Clear sky hotels says the system "uses a renewable energy source which has had the effect of making the hotel's heating and water requirements carbon neutral." Swinton Park also put in a laundry system that uses 30 percent less energy than traditional machines [9].

Apex hotels

The hotel have installed the following technologies to save energy, water and waste.

- Dual flush toilets to save water.
- Energy efficient windows to improve thermal performance resulting in less of a requirement for heating in winter and air conditioning in summer.
- Dedicated recycling unit.
- Separate walk in showers to encourage guests to use the shower instead of the bath resulting in water saving.
- Re-use of furniture and fittings after our refurbishments by donating to local charities and businesses.
- Installation of low energy light bulbs.
- Favour supplies derived from recycled materials or renewable resources

The new apex hotel at Dundee has the following features

- Key card systems control lighting, heating and air coolers when room not in use.
- Building management systems are in place to control temperatures throughout the building.
- Existing lifts have been replaced with energy efficient lifts.
- Energy saving lighting, dimmers and motion detectors are in place [10].

2.2 GERMANY

The Maritime Hotels:

In this hove natural gas or district heating is used for heating purpose. Water is heated by solar thermal collector equipped on the roofs. Water saving devices are installed on taps and showers to save water. Hotel is equipped with LED for lighting and they says: compared to conventional light sources it saves around 80% of power. Electronic control air circulators are used to power the air conditioning systems [11].

Adlon Kempinski:

Hotel has reduces 80% of its power consumption by replacing the halogen lighting with LED in 382 hotel guest rooms. Seven thousand GE LED lamps have been installed at the hotel in Berlin. This saves around 140,000 kWh per year [12].

2.3 INDIA

The Orchid:

The architecture of the hotel is designed in a manner to save the energy by passive methods. The passive methods adopted in the hotel are: the facade, plan configuration, natural lighting in the atrium and roof top. In facade, desolation and projection play a major role in reducing the surface radiation. The plan configuration is made in such a way that all the rooms are face towards the atrium, so it reduces the direct sunlight radiation. Triple glazing windows and aqua zone drinking water system is employed in the building. Key card system and energy efficient PL lamps are used to curb the energy consumption [13].

Hotel Rodas:

The rodas hotel uses a new approach to reduce the power consumption, which was a chilling tank. This tank is attached to the air conditioning unit. During off-peak hours it stores the cold energy and supply during peak hours. By this approach it reduces the work of condenser unit [14].

IN Accor:

To reduce the electricity consumption and to improve the heating and cooling efficiency the hotel have installed an efficient chiller for air conditioning system, insulated duct for heat recovery system. Besides LED lamp and CFL lamp are installed as well as an electronic ballast are installed for fluorescent tube light. Key card system is installed to access the room as well as to turn on the supply for the rooms. In order to control and reduce the water usage at sanitary services sensors are installed on all taps [15].

Hotel Oberai:

The hotel adopted various techniques to save energy and water resource as well as reuse of waste from the hotel effectively

Energy

The hotel installed a building management system which establish the efficient operation and control according to load demands and occupancy.

- The hotel pools are heated by solar panels installed on building roof tops.
- Waste heat from the chillers are recovered to heat all domestic hot water.
- A backup diesel generator is turned on approximately one hour per day during the hot summer months when the power supply fails from the distribution company. The diesel generator located in a room reduces noise pollution.

Water

- Rain water harvesting is installed on roof top
- Ground water is used for the whole hotel water supply
- Reverse osmosis is engaged to supply purified water for all domestic use

Waste

- Solid waste from the hotel is dried and used as a fertilizers in the garden
- Waste oil from the kitchen is disposed to soap manufacturing industry [16]

2.5 DUBAI

Radisson blue:

The hotel have use of biodegradable chemicals and recycling initiatives. Furthermore the hotel uses efficient air conditioning system, thermal wheel to maintain indoor air comfort [17].

Fairmont Dubai:

The hotel took very effective steps to cut the carbon emission some of them are: temperature control and building humidity settings are optimized resulting in a 17.1% reduction in greenhouse gases over the last four years. Two oil boilers are replaced with electric boilers, which cut more than 75% of carbon emission. It employed a use of thermostat in rooms to control HVAC scheduling [18].

The Kempinski Hotel Mall:

The hotel uses Eco-Smart to reduce overall electricity and chilled water consumption. To ensure the continued comfort of guests, Eco-Smart will integrate fully with the hotel's work order management system, streamlining response times to any reported issues in guestrooms [19].

2.6 AUSTRALIA

Alto hotel

The hotel initiated various power, water and waste conservation technologies. Some of them in each areas are:

Energy

- High star rating HVAC inverters, with sensor controls
- Hot water reticulation system
- Fluoro or LED lamps

Double glazing windows are used to reduce the noise from outside as well as to maintain the indoor temperature. Stud wall construction is used for interior walls to reduce noise and heat.

Water

- Water recirculation system is installed in the hotel to water wastage.
- The hotel basement has rain water storage tanks and water from basement is used for sanitary service.

Waste

In the rooms, recyclable and non-recyclable bins are placed to collect the waste. All waste from the kitchen is dumped into a compost bin. The fluorescent lamps are recycled for their mercury content and glass. The waste oil is collected and converted to bio diesel [20].

Crown plaza

The hotel have installed the following technologies to reduce the power consumption:

- Energy efficient light bulbs (LED bulbs)
- Since the demand of the hotel is variable, for the effective control of pumps and motors variable speed drives are used. This saves 30% of its energy use.
- Centralised temperature control depends on occupancy is achieved through building management system.
- A sensor is installed at each guest rooms to manage the light and temperature.
- Energy efficient air dryers are used.
- Special shower jet heads and flow restrictors are used to reduce the water wastage.
- Conventional flush toilets are replaced with dual flush toilets
- Traditional urinals are replaced with water less urinals [21]

Green hotelier:

Water efficient low- flow shower heads and aerator taps are used to save 30% to 40% of water usage. Grey water recycling plant is installed in the hotel to collect and supply the water from different zones like kitchen, sanitary service, guestrooms etc. [22].

2.7 USA

The Hyatt at Olive 8’s:

The hotel have installed green roof to reduce the storm water runoff by 75%. It also reduces the power required to heat and cool of the hotel [23].

The Proximity Hotel:

The hotel is located at Greensboro which has limited water resource hence it have installed high efficiency plumbing device, which saves 33% of water in the first year. Hundred solar panels have installed on the roof top and used to supply hot water to entire hotel. It diminishes 50% of hot water heating use [23].

Hotel Indigo:

The hotel have procured HVAC system and variable refrigerant volume heat pump to maximize the building energy performance. These systems are 30% more efficient than the air conditioning system used in guest rooms. This system also helps in improving the indoor air quality as well as comfort of the occupant [23].

Bardessono Yountville:

A hotel space heating and domestic water heating is supplied by ground source heat pump system. The system installed also recovers the air conditioning waste heat for domestic water heating during the summer. Solar panels are installed on roof tops and generate power. This power is utilized for hotel lighting and small power equipment. These system almost saves 40% of power utilization and saves $90,000 in a year [23].

The literature review having laid foundation to existing technologies paved way to discuss furthermore on other strategies such as ventilation systems. The report will now set focus on the importance of improving the indoor air quality system such as through the incorporation of ventilation systems and then the report describes the methodology used for the installation of a ventilation system in a hotel.

3 INDOOR AIR QUALITY

Indoor air quality indicates the quality of air in the living area of the houses, commercial buildings, hospitals, etc. Characteristic of air in the building play an important role in the physical health of the residents, some properties of air are: gas type, temperature and humidity of air, volume, pressure and speed. The quality of air can be determined by observing the health of an occupier and the comfort in the living place. In this technological world, living standard of people has improved and started to spend 90% of their time in indoors, where they are frequently brought in to indoor air pollutants [24]. Over the past several decades our exposure to indoor air pollutants is believed to have increased due to variety of factors such as air tight building, shortage of sufficient ventilation, domestic impurities like interior furnishing, smoking tobaccos, burning fuels, pets, etc. In recent years comparative risk studies performed by EPA and Science Advisory Board (SAB) have consistently ranked indoor air pollution among the top five environmental risks to public health. As a result of these studies people began to realize that the indoor air quality is important to comfort and health [5].

3.1 AIR QUALITY ISSUES AFFECTING THE BUILDING & HUMAN HEALH

- Sick building syndrome
- Moulds and moisture
- Dust mites
- Tobacco smoke
- Carbon monoxide
- Nitrogen dioxide
- Volatile organic compounds

3.1.1 Sick Building Syndrome (SBS)

Sick building syndrome represents the intense health comfort issues which is tied up to the time settled in the building. This problem could occur throughout the building or may be in specific zone/room. A report suggested that there is 30% of new and remodelled building worldwide may be subjected of complaints related to poor indoor air quality (1988, World Health Organisation) [25]. The sick buildings are generally energy efficient and characterized by airtight envelopes.

Figure 1: Sick building Syndrome [64]

SBS occurrence

Most commonly it occurs in open plane office and also in the place where the people is densely occupied. Some of the places are:

- Schools
- Libraries
- Museums [26]

Causes of SBS

- Poor ventilation and cleanliness
- Low humidity
- High temperature or change in temperature throughout the day
- Poor ambience or flickering of light [26] [27]

Syndrome of SBS comprises of

- Headache, dizziness and nausea
- Odour
- Sensory irritation of skin and upper airways, along with headache and abnormal taste
- Lower airway and gastrointestinal symptoms
- Cold, asthma, productive cold and fever [26] [27]

3.1.2 Moulds and Moisture

An average family produces 15 litres (26 pints) of water vapour each day, partly via perspiration, partly through breathing, but also from cooking, bathing, washing and drying clothes [London Electricity] [28].

Figure 2: Condensation on walls [65]

The condensation on walls and windows are the signal for moisture content in buildings. When this moisture is present for a long period or it is not properly controlled by a systems, this will lead to dampness. Dampness can also be caused by water attack either from in-house sources (e.g. leaking pipes) or out-house sources (e.g. rainwater) [29]. As a result of this it turns back to be a key factor for the growth of fungi and moulds. Moulds and fungi are exist in nature and are fundamental for the fall down of leaves, wood and other plant debris. In a building, they are commonly find developing on wood, dry wall (plaster/gypsum), fabric, ceiling tiles, and carpeting [30][5]. Moulds are almost ubiquitous in indoor environment and play an important part in life cycles. They are the primary forces in assisting with decomposition of organic materials. Air bone moulds in indoor environment are responsible for human respiratory allergies [31].

Figure 3: Mould growth on windows [66]

The presence of moulds doesn’t cause problems but when it is inhaled by the occupants or people it will cause health issues.

The most common syndrome of moulds comprises of [31] [30]

- Eye irritation
- Cough
- Headache
- Respiratory infections and asthma
- Skin, throat and lung irritation

The best method to avoid the occurrence of mould in the building is to keep the humidity level between 30% and 50%. This could be accomplished by [31]

- Installing dehumidifiers
- Insulating pipe, window, wall and roof to prevent condensation
- Drain out any floods or arrest the pipe leakage immediately
- Keep in good condition of air conditioning systems

3.1.3 Dust mites

Dust mites are microscopic arthropods creature approximately 0.35mm long with eight legs, grows in the area of high temperature, high relative humidity and insufficient ventilation. It is naked to human eye [32]. There are thirteen species of mites whose life cycle is about two to four months. In buildings they live their whole life dark-corner dust bunnies, bedding, carpets, hatching, growing, and eating. On average, adults and especially children spend 90% of their time in the home [5]. Children are more uncovered to many asthma triggers in their homes. In UK the most commonly allergen causing asthma is dust mites. Allergens of dust mites are proteins found in the mite's faeces. The proteins causes severe allergic counter to fatality [33].

Figure 4: Dust mites [67]

To avoid asthma it is necessary to keep home or building free from dust mites. This could be accomplished by following methods [34]

- Keep the humidity level of a home or building below 50 by using dehumidifiers or air conditioning systems.
- This could also be achieved natural method by opening the windows for one hour to discharge the humidity.
- Replace carpets if the people in is suffering from asthma or it should be chemical cleaned by benzyl benzoate.
- Wash bed in hot water.

3.1.4 Tobacco smoke

Tobacco smoke refers to smoking as well as being exposed to others cigar, cigarette or pipe smoke. These kind exposed smokers are called as passive smokers or second hand smokers or involuntary smokers [35].

Tobacco smoke comprises of minute solid particles and gases. Tobacco smoke liberate more than 4000 various chemicals in to air. Among which 30 to 60 chemicals are recognized to cause cancer in both humans and animals. The composition of minute solid particles are 10% of tobacco smoke which include tar and nicotine [36]. The major gas liberated from smoke is carbon monoxide. The chemical which cause cancer in animals are nitro-sodium-methylamine and acrylonitrile. According to EPA estimates children under 18 months of age, passive smoking causes between 150,000 and 300,000 lower respiratory tract infections, resulting in 7,500 to 15,000 hospitalization each year [5]. It also estimates that exposure to ETS increases the number of asthma episodes and the severity of symptoms in 200,000 to 1 million children annually [37].

Figure 5: **Tobacco smoke [68]**

Some health illness caused by tobacco smoke are

- Nose and throat irritation
- Breathing problems
- Lung and other cancers
- Cardiovascular diseases [31]

3.1.5 Carbon monoxide (CO)

Carbon monoxide is a colourless, odourless gas and tasteless gas. It is the most intense toxic indoor air contaminants [38]. Once emitted in to the atmosphere CO is slowly oxidised to CO_2. It is produced by the partially burnt fossil fuel. Inhalation of carbon monoxide reduces the supply of oxygen to the rest of the body. Effects will vary depends on the amount of inhalation. At low level its effects are like headache, weakness, confusion, vomiting, faintness and fatigue [39]. This symptom is sometime confused with flu or food poisoning. At moderate level its effects are like decrease in brain function and damage the vision. A high level of carbon monoxide inhalation leads to death [5].

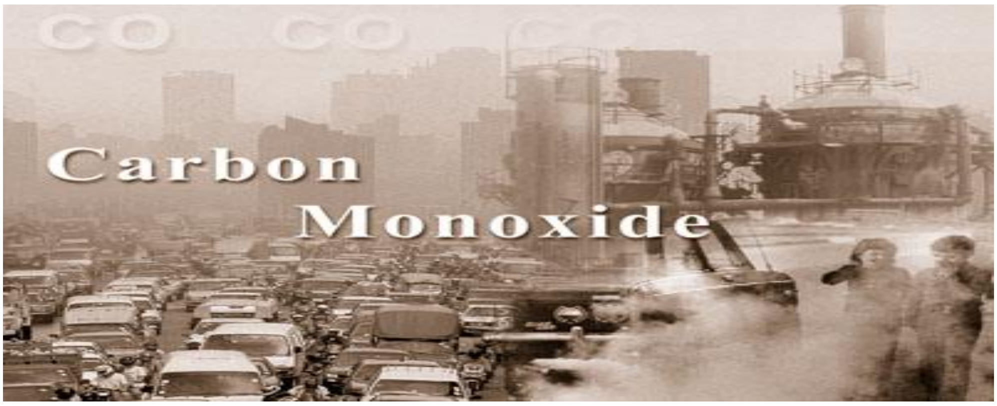


Figure 6: **Sources of CO [69]**

Sources of carbon monoxide are:

- Badly installed or poor ventilated cooking or heating appliances which use fossil fuels, including gas, coal, wood or paraffin.
- Cigarette smoke.
- Parking vehicle in an attached garage of the home may cause carbon monoxide to get inside. [31]

3.1.6 Nitrogen dioxide (NO_2)

Nitrogen dioxide is a harmful gas which is highly reactive to oxygen and corrosive. The oxides of nitrogen comprise several gases, including nitric oxide (NO) and nitrogen dioxide (NO_2). In atmospheric air NO_2 is probably the most important for human health [40]. The main sources at indoors are: absence ventilation for combustion devices for example: burning oil and wood inside, unvented gas stove, tobacco smoke and heaters. Health effects associated with nitrogen dioxide are: eye, nose and throat irritation. Extreme exposure to NO_2 may cause pulmonary edema and diffuse lung injury [31].

Figure 7: **Source of NO$_2$ [70]**

3.1.7 Volatile Organic Compounds (VOC)

Substances which contain carbon and evaporates at room temperature are called as volatile organic compound. Some VOC has adverse effect on human health they are: benzene, carbon tetra chloride, hexane, methylene chloride and chloroform [41] [42]. Some VOC compounds are highly reactive with a short atmospheric lifespan, others can have long lifespan. Source of VOC are classified in to indoor and outdoor, some of its pollutants are shown below [43].

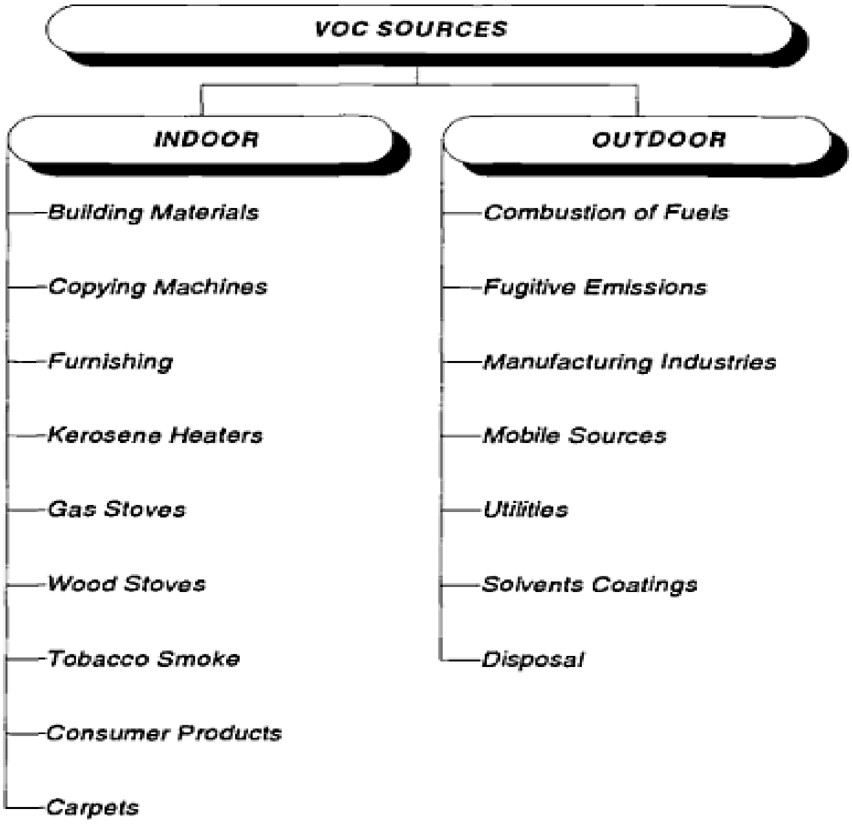


Figure 8: **Outdoor and indoor VOC source model**

Indoor movements which release VOC are glues, cosmetics, paints, varnishes, cooking as well as tobacco smoke [43].

Figure 9: **Indoor VOC sources (source: http://www.airpurifierguide.org)**

Some of short-term and long-term intense to high stage of VOCs are

Short-term effects are:

- Eye, nose and throat irritation
- Headaches
- Nausea or vomiting
- Dizziness
- Worsening of asthma symptoms [31]

Long-term effects are

Increased risk of

- Cancer
- Liver damage
- Kidney damage
- Central nervous system damage [31]

4 NEED FOR VENTILATION SYSTEM

In modern technology era use of electric power supply, number of vehicles, different amenities has increased due to population increase, improved in living standard of people, etc. This increases cause decrease in: air quality, water availability, increase in Green House Gas (GHG) emission, water pollution, etc. Especially increase in greenhouse gas emission cause a drastic change in climate around the world.

As discussed earlier in the chapter3, in most of the cases the main problem is no proper ventilation in buildings. To overcome the above negative impacts on the environment, it is necessary to have a ventilation system in every home or building to have a healthy life.

4.1 VENTILATION STRATEGIES

While considering the ventilation there are different strategies in it. Some of them are:

- Natural ventilation
- Passive stack ventilation
- Mechanical extract ventilation
- Mechanical ventilation with heat recovery

4.1.1 Natural ventilation

Natural ventilation is also known as passive ventilation. This could be achieved by using windows. Occupant can control the ventilation by opening or closing it. By opening the windows, large amount of air will get in and provide cooling during summer season. But during winter season, opening windows let the heating energy to be escape from the building and leads to energy loss [27].

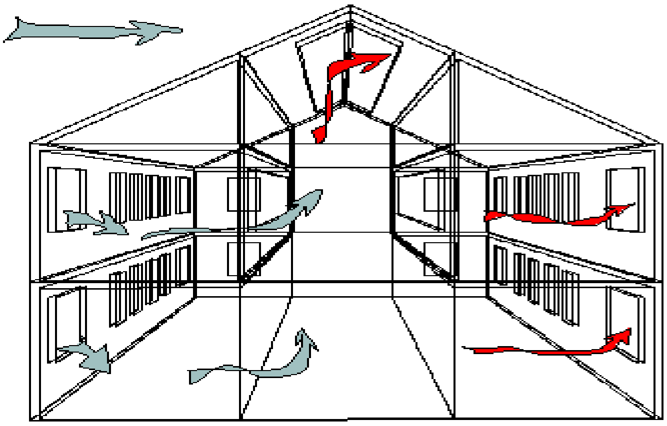


Figure 10: **Natural ventilation through windows (Source: http://www.edsl.net)**

Advantages

- Installation cost is less
- Provide some ventilation[27]

Disadvantages

- Ventilation rate cannot be controlled
- Heat loss occurs by opening the windows
- Uneven distribution of air takes place
- It cause noise pollution
- Provide a path to outdoor pollutant to get enter in to the building [27]

4.1.2 Passive stack ventilation

Passive stack is the non-mechanical system, which uses a duct system to send stale and warm air outside by the stack effect principle. Stack effect is the movement of air results from the difference in temperature and moisture between in and out of the building [44]. The air flow should me minimum through the duct. There should be no more than two bends per duct and each bend should not exceed 45° [45]. Duct diameters are typically between 80 and 125 mm [46]. Fresh air enter in to the through slits and by opening windows.

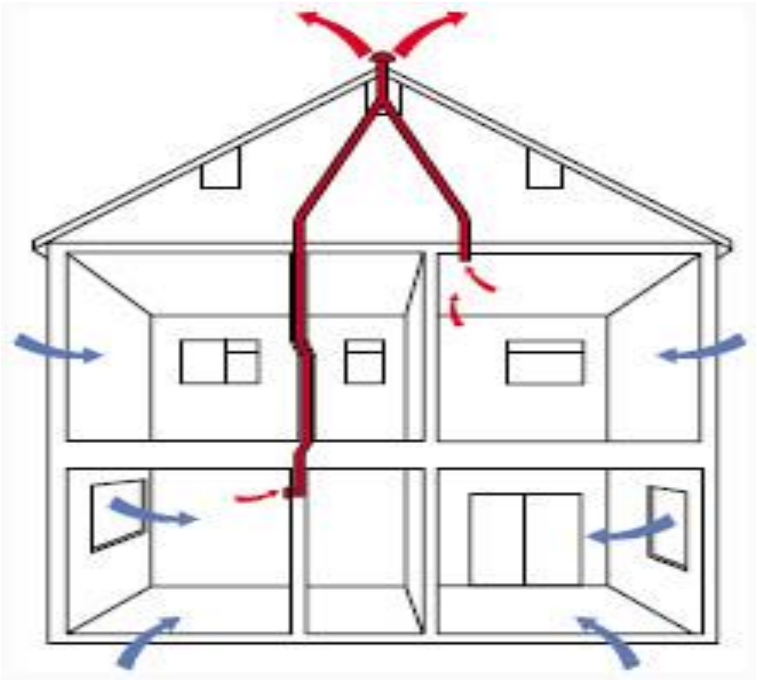


Figure 11: **Passive stack ventilation (source: http://www.tek.kingspan.com)**

Advantages

- Less installation and running cost
- Continuous passive ventilation [47] [27]

Disadvantages

- Proper space is required for duct installation
- Heat loss will occur through the vent provided
- Incoming cold air should be heated
- Back-draught may occur [47] [27]

4.1.3 Mechanical extract ventilation

It is a continuous extraction system of stale and moist air from rooms like bathrooms and kitchens and exhausted out through the duct. The extraction of air takes place from the centralized unit comprises extract fan located at roof ridge [48]. The fresh air is supplied by the background ventilators (slit) or through the building fabrics in less air tight buildings.

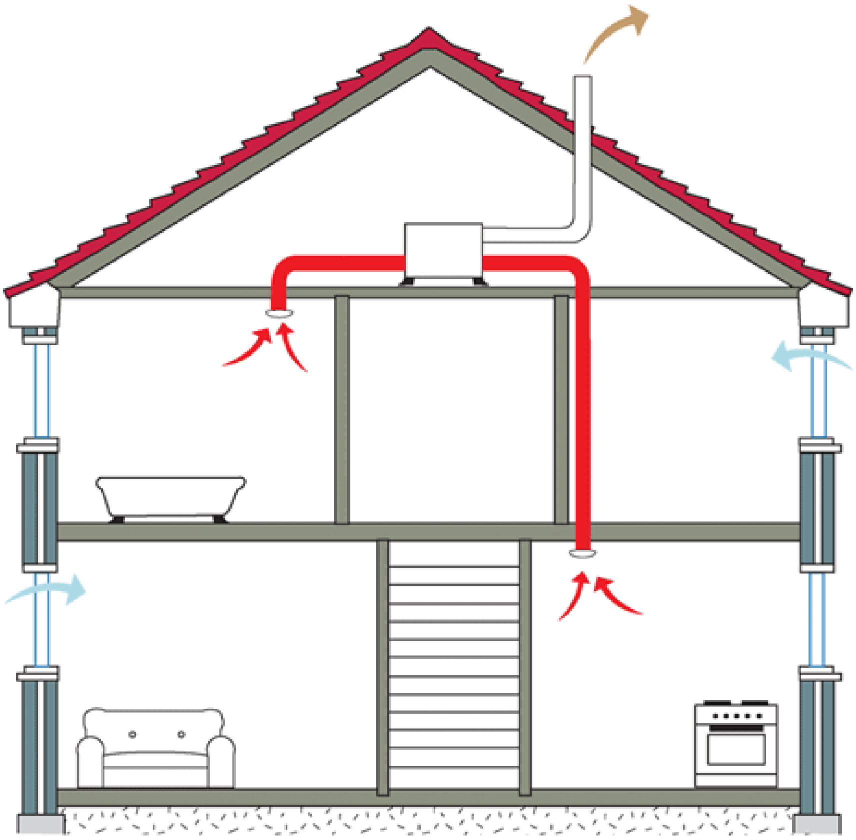


Figure 12: **Mechanical extract ventilation system(source: http://www.homeventilation.co.uk)**

Advantages

- Condensation preventer
- Less cost and easy to install
- Moist and stale air exhaust directly [49]

Disadvantages

- Regular maintenance is required
- Heat loss occurs through vented warm air
- Fan noise might be an issue
- Poor distribution of fresh air [49]

Among the above ventilation strategies, MVHR system finds to be a best solution. The reason behind is discussed in next chapter.

5 MECHANICAL VENTILATION HEAT RECOVERY SYSTEM (MVHR)

Mechanical Ventilation Heat Recovery (MVHR) is simple and packed air management unit which provides good ventilation with the efficient removal of pollutants in the buildings as well as greater efficiency in heat recovery from the exhaust air.

5.1 OPERATION OF MVHR SYSTEM

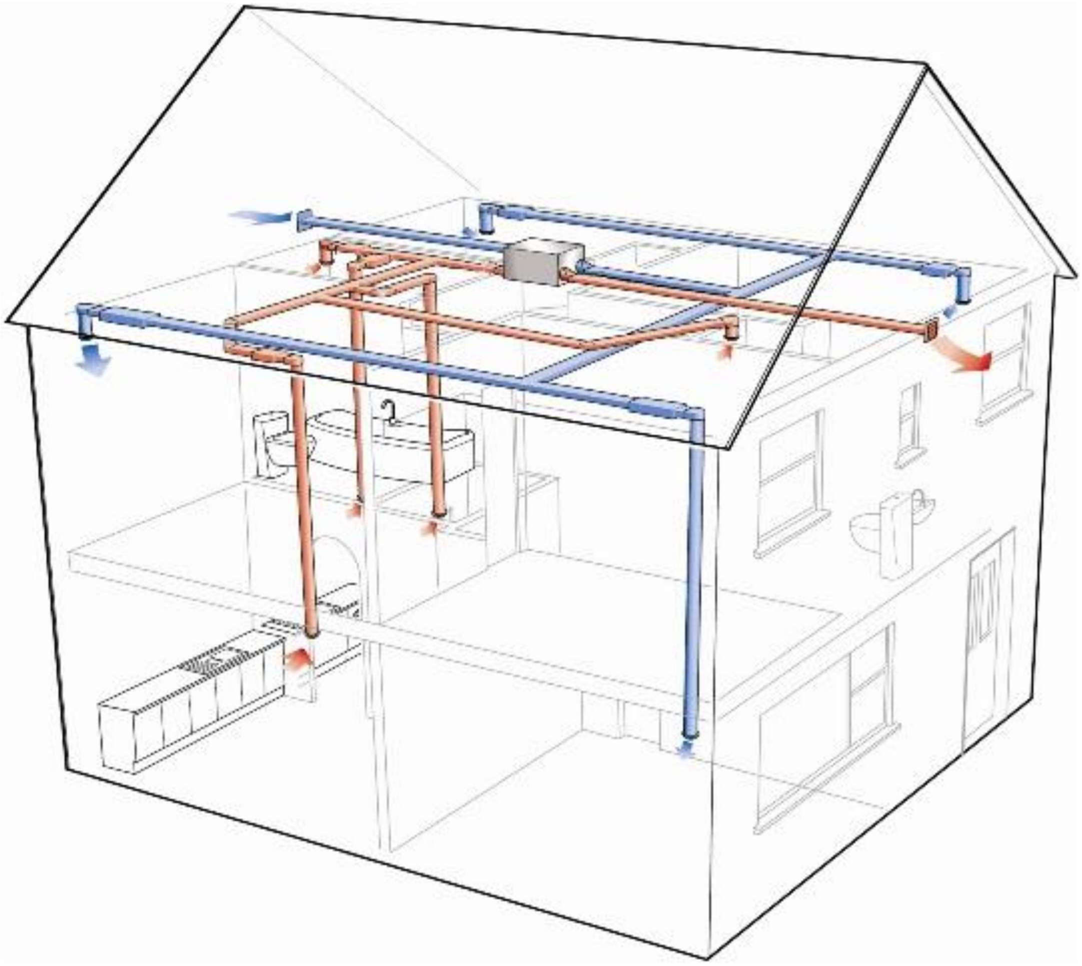


Figure 13: **MVHR system in domestic sector (source: http://www.polypipe.com)**

A supply fan in the unit draws the atmospheric air and air filter removes dust and other pollutants. This pollution free air is passed on to the heat recovery unit. Concurrently warm stale and moist air is extract from the building zones like kitchens and bathrooms by the extract through duct system and passed on to the heat exchanger unit. Thus, heat exchanger transfer the heat of the extracted air to the incoming air. Therefore warm fresh air will be delivered at human comfort to the zones like living room and bedroom. Well-designed MVHR systems are significant in air tight buildings to establish good indoor air quality, a comfortable draft free environment and lower energy demands. The system should be balanced by maintaining an equal supply and exhaust flow rates, so that it prevents any pressure difference that occurs between inside and outside of the building [50] [51].

5.2 ADVANTAGES OF MVHR SYSTEM

Some important advantage of using MVHR system comprises control of

- Relative humidity
- Thermal comfort
- Air quality and
- Energy saving [52]

Relative Humidity (RH)

Relative humidity is the term used to represent the amount of water vapour that can hold by a volume of air at certain temperature in percentage of the amount that is capable of holding [53].

$$\text{Relative Humidity (RH)} = \frac{\text{(Actual Vapor Density)}}{\text{(Saturation Vapor Density)}} \times 100\%$$

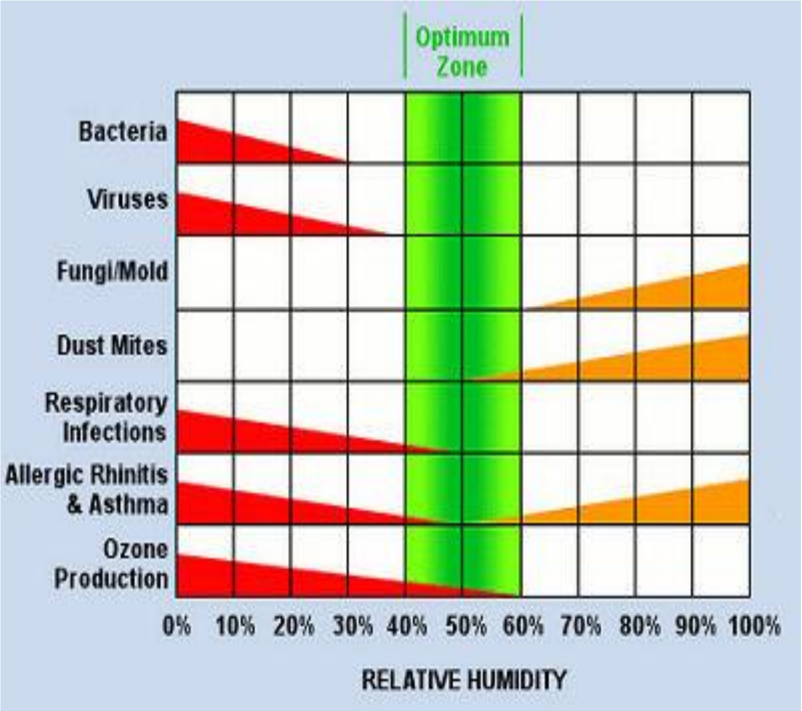


Figure 14: **Relative Humidity (Source: http://www.air-conditioning-advice.com)**

Hence the amount of moisture which can occur for a given volume of air depends only on temperature and is expressed in Kg per Kg of dry air. Discomfort or problem will occur only when the relative humidity is very high or very low. In general most people will feel comfort with the RH in the range of 40% to 60%, couple with temperature in the region of 18C to 22C. Low level of relative humidity will result in sore throats and dry eyes. Condensation occurs only when the air volume has high RH and approaching its saturation point as well as when the air temperature get lowered and tends to reach its dew point results it suddenly start condensing cold surfaces like walls and windows. As discussed in section 3.1.3 of chapter 3 high RH cause dust mites, therefore to avoid this at least exhaust ventilation system has to be installed at bathroom and kitchen or MVHR has to be installed in the building to provide proper ventilation and live a healthy life [53] [54].

Thermal comfort

Ventilation play a major role in providing comfort to the occupant in the building. The thermal comfort a person experiences is defined as 'that condition of mind that expresses satisfaction with the thermal environment' [British Standard BS EN ISO 7730] [55]. It determines the psychological state of the occupant whether they feel hot or cold. When the rate of heat loss from the body is low occupant feel hot and when the heat loss is high they feel cold [56]. Thermal comfort varies from person to person based on their clothing, metabolic rate and air velocity in the zone. The metabolic rate varies from the activity carrying out, for example: cooking, swimming, jogging, etc. each clothing has its thermal value, based on climate the clothing will change. It cannot be measured in degrees but one possible way is to give their status like unpleasant, shivering, pleasant, acceptable and hot.

Heat losses from the body is transferred to the indoor environment by three principles 1) convection 2) radiation and 3) evaporation. In convection heat loss takes place from outer surface of clothed body to air. Whereas in radiation heat loss takes place from outer surface of clothed body to its environment and in evaporation heat loss takes place from the skin [57].

Thermal comfort is a combination of environmental factors and personal factors. Parameters considered in environment and personal are shown in the figure:

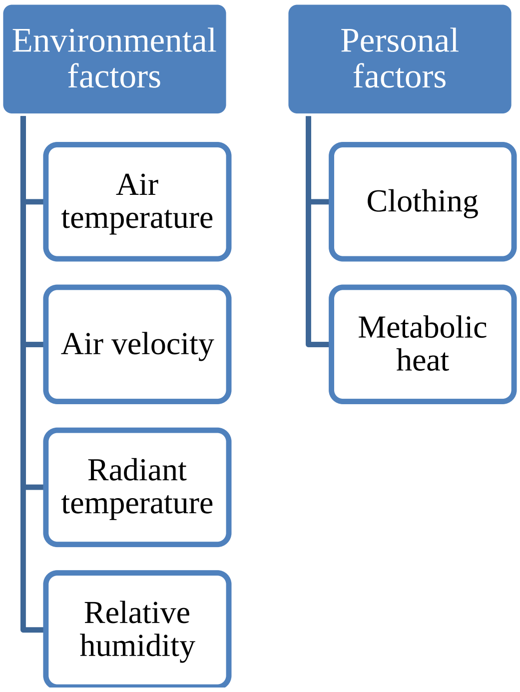


Figure 15: **Environmental and Personal factors affecting thermal comfort [57]**

Human comfort condition depends on air temperature and relative humidity exist in a place. A figure shown below is a psychrometric chart which represents the comfort level of human during summer and winter. The variation in temperature occurs mainly due to the clothing level at two different season. A comfort temperature for human in all round the year would be 23C or 74F [58].

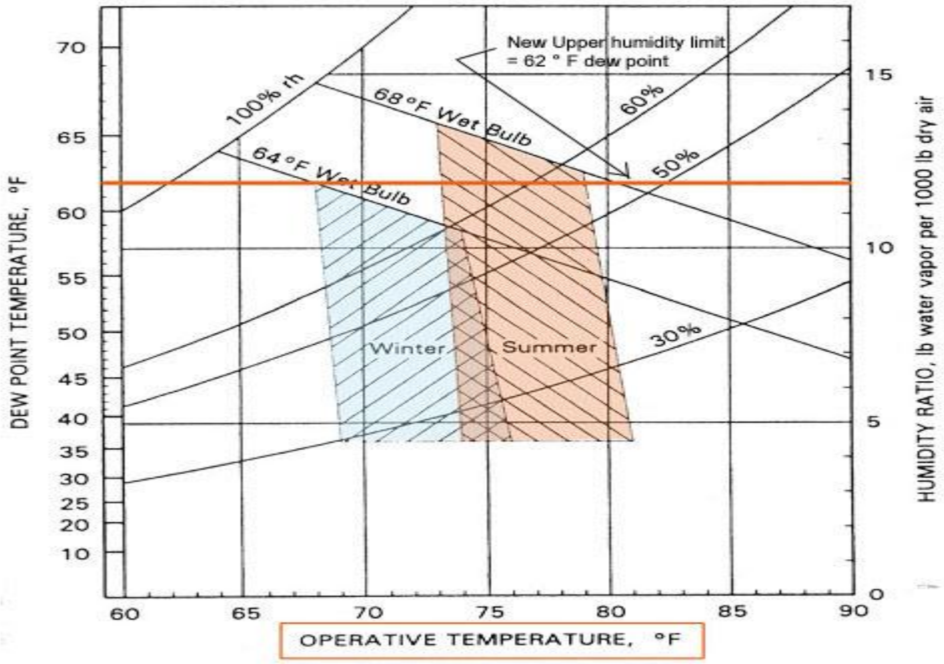


Figure 16: **Winter and summer comfort** (**Source: http://isvox.blogspot.co.uk**)

To maintain the thermal comfort in a building all-round the year needs necessary cooling and heating at desirable seasons. Therefore use of MVHR system with heating and cooling over summer and winter helps to accomplish the thermal comfort.

Air quality **[50]**

- Exhaust and supply do not get mix in heat exchange, so it ensures continuous supply of fresh air.
- No radical CO_2 spikes
- Charcoal and pollen filters are used to provide pollution free supply air as well as to avoid diesel fumes and rural odour.

Energy saving **[50]**

Heat recovery unit in MVHR transfer the heat from stale and moist air in the rooms to the supply air. Hence thirty percentage of heating bill could be save by installing MVHR system in the building.

5.3 DISADVANTAGES OF MVHR SYSTEM [51]

- Proper filter maintenance or replacement check is required regularly to avoid blockage as well as stale air.
- Depend on electricity for its continuous operation.

5.4 MVHR SYSTEM TYPES

In MVHR heat exchanger system is mainly classified into

- Plate heat exchangers
- Thermal wheel

Plate heat exchangers

Plate heat exchanger is commonly employed for heat transfer in MVHR system. Plate heat exchanger consist of number of thin, thermally conductive material like aluminium, resin coated paper etc. theses plates are arranged in parallel to form a stack and each plates are separated by certain spacing. Here two air streams pass through the carrier formed between two plates [59]. While flowing through the channel it never get mix-up. Sensible energy from warm stale air at one side of exchanger is passed on to the cool air flowing at other side of the exchanger.

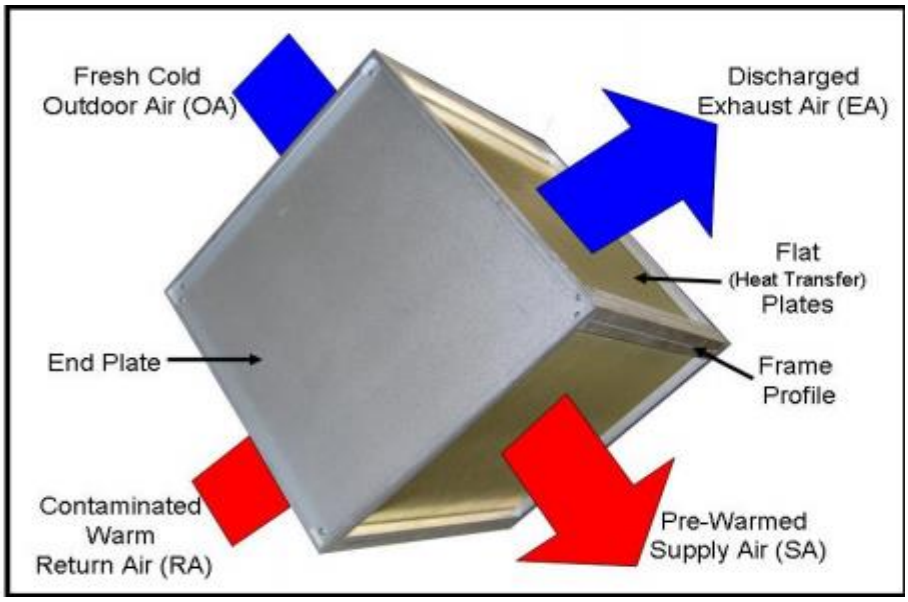


Figure 17: **Cross flow plate heat exchanger (Source: http://www.xetexinc.com)**

In cross flow plate heat exchangers exhaust air and supply air flow 90^{o} in relationship to each other. It is diamond shape configured square core rotated at 45^{o} to hold the duct work. The entire unit is enclosed in a closely packed box with two centrifugal fans and also a filter to remove any particulates or dust. The BRE Digest on MVHR systems referred to by the UK Building Regulations [BRE 1994] states that: 'Air filters and air supply and extract grilles will probably need to be cleaned at least two or three times a year; the heat exchanger in MVHR systems annually [59] [60].

Advantages

- Heat exchanger unit is stationary
- Low cross contamination
- Large temperature range [27]

Disadvantages

- Continuous fan energy is required to overcome the pressure drop
- Chance for overheating in summer if no bypass mode is provided
- Frost will occur during cold climate when there is condensation at exhaust side
- Use of filters increase fan power consumption [27]

Thermal wheel

Thermal wheel got various name such as energy recovery wheel, rotary generator or rotary heat exchanger. It is a pervious or penetrable wheel through which exhaust and supply air can flow [61]. Wheel is made up of layers of aluminium foils or flat composite materials which is folded and sandwiched of uniform width to form a smooth surface as well as to form a narrow channel to establish a laminar flow [62]. The wheel can be cleaned by spraying compressed air or by hot water as well done by vacuum-cleaning

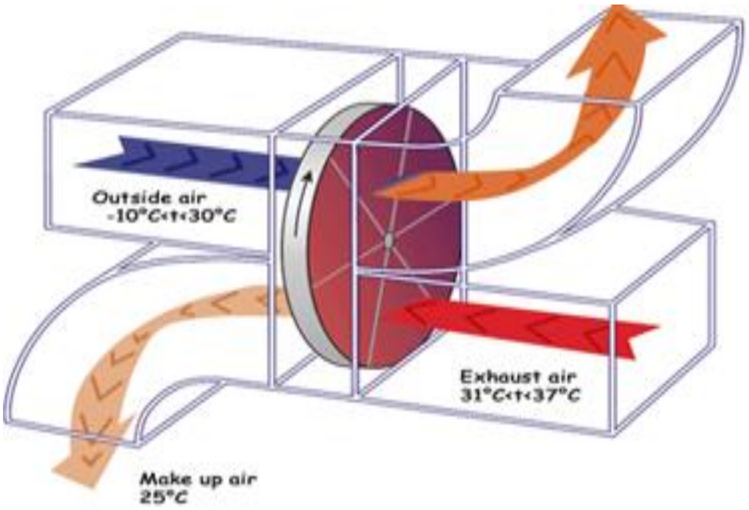


Figure 18: **Thermal wheel (Source: http://www.datacenterknowledge.com)**

In heat recovery unit energy recovery wheel is used to warm up the intake air from atmosphere by transferring the heat from exhaust air. To accomplish this, wheel has to rotate between the two air flow streams. The wheels generally operate by rotating at between 15 and 20 revolutions per minute to recover 50% to 80% of thermal energy [63].

The rotary generator helps to balance the humidity inside the house in the winter on a healthy level between 35 -50 % by recovering some of the humidity on the air intake and air exit volumes. It special feature is it could operate even in very cold temperature without freezing [62] [63].

Advantage

- High heat transfer efficiency
- Both sensible and latent heat can be transferred
- Low fan energy consumption
- Efficiency of the system can be varied by employing variable speed drive [27]

Disadvantages

- Additional energy is needed to rotate the wheel
- Air intake and air exit duct should be close to each other [27]

6 METHODOLOGY

The effective modelling of hotel environment was done in ESP-r with the knowledge gained from the literature review.

Initially the project tend to be a continuation of a feasibility study for CCHP in the hospitality sector but according to the client interest, the project's focus shifted towards the recovery of waste heat exhausted from the building. This ended up with the installation of MVHR system for the building.

The floor plans was obtained from the client and attached in the Appendix-A. The dimensions of sections like restaurant, lobby, reception, bar, plant room, bedroom etc. was measured manually.

In ESP-r, the model begins at geometry phase and ends at defining the surface connection and boundary in order to run the simulation. Polygon method was chosen to model each zone. On the other hand construction material and its U-value play an important role in indoor environment comfort. Hence careful and accurate selection of material was made. The spreadsheet calculation was carried out to define sensible and latent gain of lighting, people and equipment. Finally the boundary and surface connection of each zone was defined to carry out the simulation process.

Mechanical ventilation system was modelled with the knowledge obtained from the thorough review of MVHR example models in ESP-r as well as literature review on MVHR system. The description and assumptions made for modelling of zones and plant system is described in the chapter:

The energy standard of the building was assessed by comparing annual power and gas consumption in kWhr /m^2 and annual CO$_2$ emission from the building with the energy bench mark TM46:2008.

The electricity consumption of the hotel was measured and power factor over each month was calculated to view the effective utilization of power. The energy delivered to the zones by duct system was compared with the electricity consumption of the hotel and prove the MVHR system was effective to the hotel.

7 MODELLING

7.1 CONTEXT

A four storey hotel- holiday inn as shown in the figure: 19 located at the latitude and longitude difference of 55.5N and 4.2W in theatreland-Glasgow.

Figure 19: Holiday inn (Source: http://www.ga-taxis.co.uk)

It comprises:

- 100 guest rooms over 4 floor
- Restaurant
- Bar and lounge
- Meeting rooms at ground floor
- Laundry and elevator facilities

The hotel was constructed on mid of 1990s. The construction materials used for this site are: plasterboard, breeze block, part insulated cavity, brick face build. All windows are wooden framed double glazing. Rock wool insulation of 300mm is put on the loft to reduce the heat loss through it. All systems are operating independently. Key card technology is using in the hotel to access the electric supply and guest rooms.

Common ground floor areas are heated by gas fired wet central heating through built in radiators. Guest rooms and meeting rooms are heated and cool by condensers. Hot water to the hotel is supplied from the storage tank which is fed by gas fired water heaters.

The Kitchen servicing operate between 06:00 and 23:00 which utilises both gas and electricity for its facilities. The hotel mainly has business clients during the week and thus comparatively few guests remain in their rooms during the day. The hotel is part of the 'Green Tourism Business Scheme' and is operated in a proactive 'Energy Aware' manner.

7.2 MODEL DESCRIPTION

ESP-r is a building performance energy modelling software which has certain distinct features through which one can assess the building’s thermal, air, mean radiant, wet bulb temperature, gaseous emissions, relative humidity, indoor environment comfort, etc.

In ESP-r the first stage in developing the model starts at geometry phase. There are different options to model a building in ESP-r, some of them are: polygon, rectangular, 3D model and bitmap.

The hotel rooms are created as a zone by polygon approach. To reduce the software complexity as well as to bring a better result certain assumptions are made at both floors, some of them are: Conservatory, lounge, bar and restaurant are considered as one zone. Further reception, foyer and office are coupled as another zone. Due to certain constraints, only one storey was constructed in ESP-r, the constraints are given below

- Zone modelling should start and proceed in anti-clockwise direction, otherwise it takes top surface as a ground and bottom surface as a ceiling.
- It cannot hold more than 58 vertex coordinates in a single zone.
- ESP-r has a rule that every surface has one boundary condition.
- Only 72 zones/ sections could model in ESP-r

According to the ground floor plan, the building consist of 19 rooms. By the above assumptions the ground floor model in ESP-r as shown in figure:20 consist of thirteen zones, which includes restaurant, kitchen, two meeting rooms, office, plant room, pathways etc. Each zone has own origin point. The total ground floor area of the ESP-r model 875.3613m^2 is similar to the actual building.

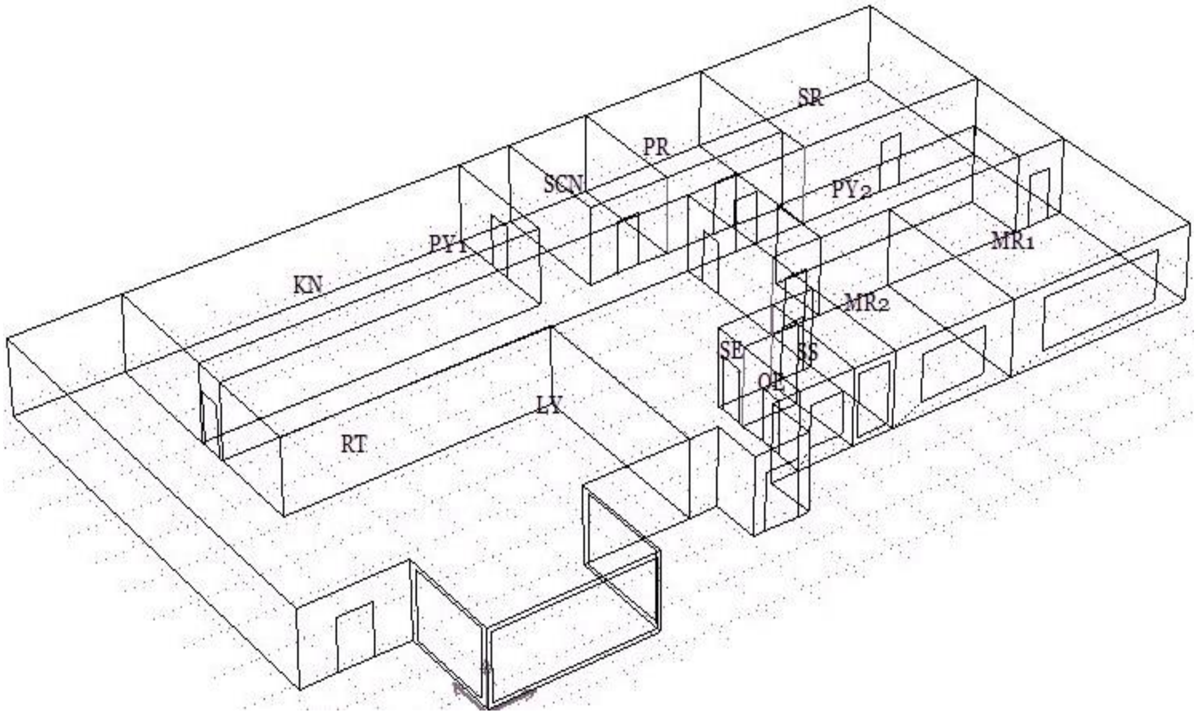


Figure 20: **Ground floor model**

Similarly the first floor plan of the hotel consist of 29 bedrooms. In the modelling the size of the bedrooms are altered to reduce the number of bedrooms. According to this first floor model as shown in the figure:21 comprises sixteen zones which includes seven double bedrooms, four master bedrooms, three single bedrooms and pathway with the total first floor area of 850.4532 m^2

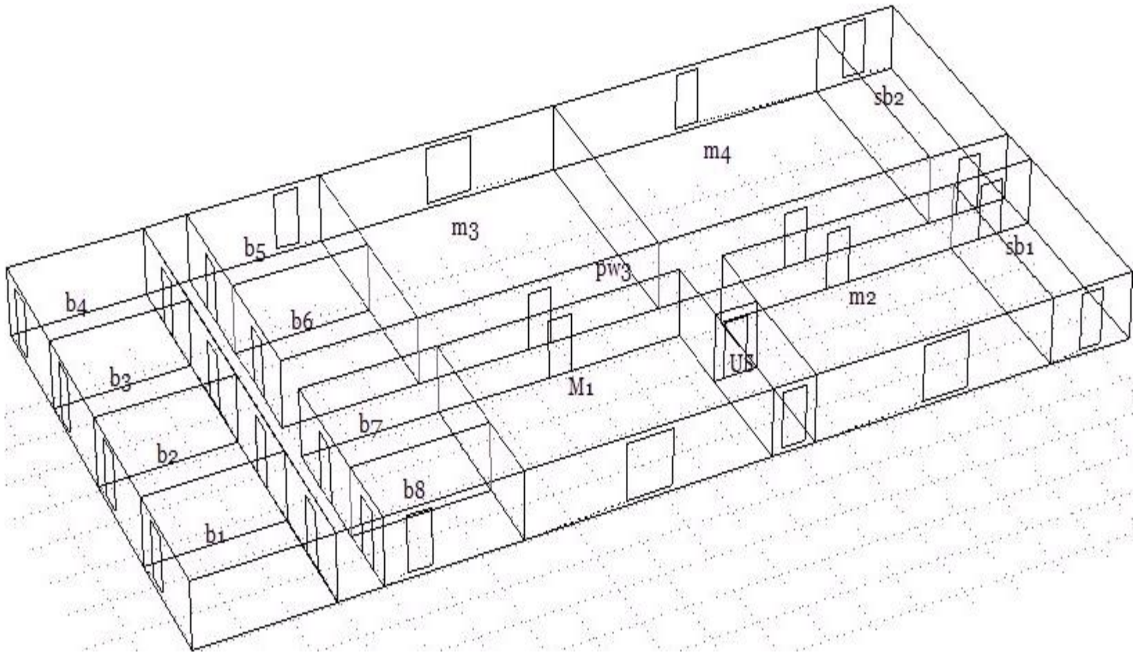


Figure 21: **First floor model**

The hotel is exactly modelled to a topographical location of the hotel with the ground reflectivity of 0.20. Climate pattern selected for the analysis is std. UK climate and assessment year is 2013. The final model of the hotel with ground floor and first floor are shown in the figure: 22.

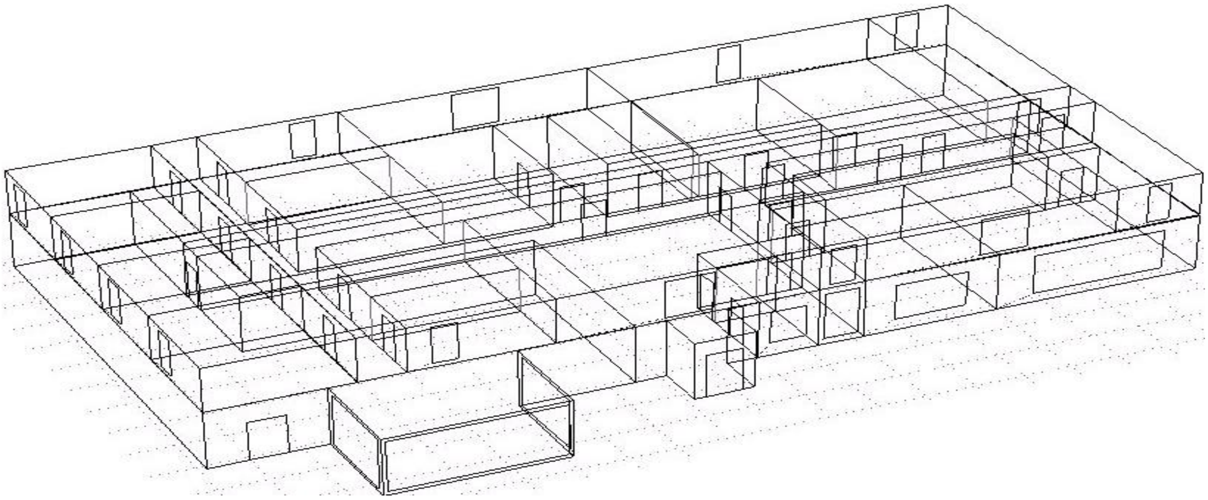


Figure 22: **Holiday inn model**

In further sections of this chapter, the geometry, construction and casual gain details of the zones connected to the plant system was described.

7.3 GEOMETRY DESCRIPTION

RESTAURANT

It is composed of 19 surfaces including 3 exterior facing windows at conservatory and two doors, were one door gives the entrance to the restaurant and the other one is linked with the pathway. The total surface area of the restaurant is 235m^{2}and its volume is 727m^3. The model of the restaurant is shown in the figure23.

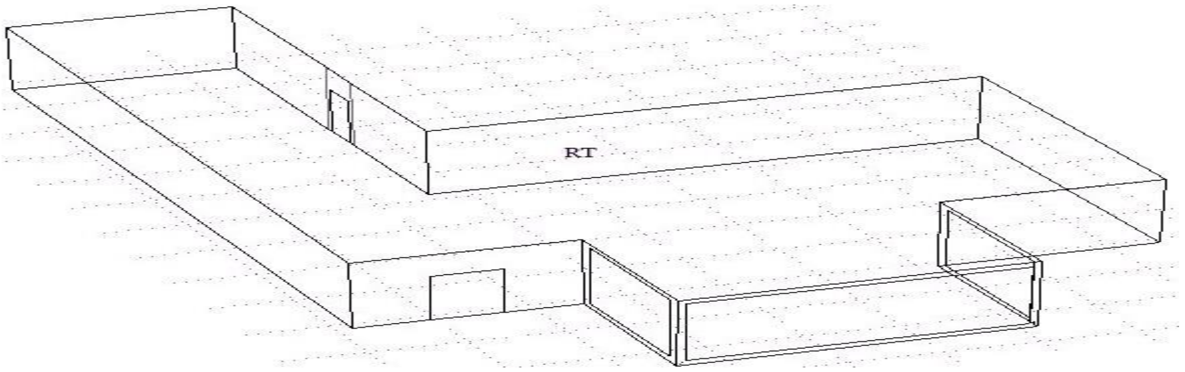


Figure 23: Model of restaurant

KITCHEN

It is composed of 7 surfaces including one door, were it gives an entry to kitchen linked with the pathway. The volume and total surface area of the kitchen is 259m^3 and 83.6m^2. The model of the kitchen is shown in the figure24.

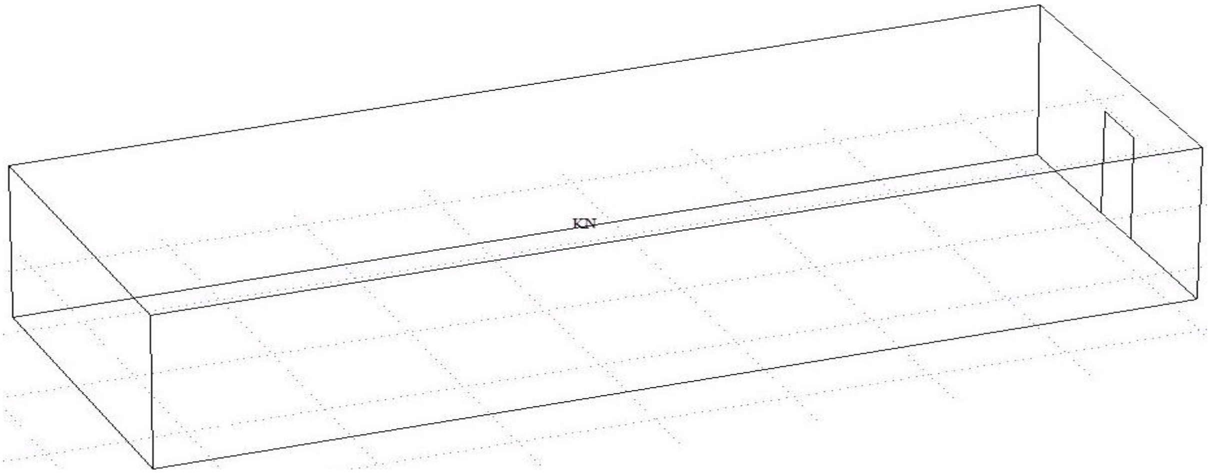


Figure 24: **Model of kitchen**

OFFICE

It is composed of 8 surfaces including an exterior facing window and a door. A door gives a way to enter in to the office is linked with lobby. The volume and total surface area of the restaurant is 26.6m^3 and 8.57m^2. The model of the office is shown in the figure25.

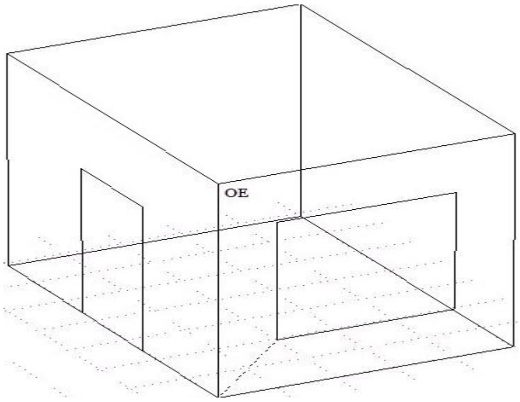


Figure 25: **Model of office**

LOBBY

It is composed of 22 surfaces including 5 doors. Four doors are linked with their respective zone for an entry and another one to enter in to the hotel. The volume and total surface area of the restaurant is 476 m^3 and $154m^2$. The model of the lobby is shown in the figure26.

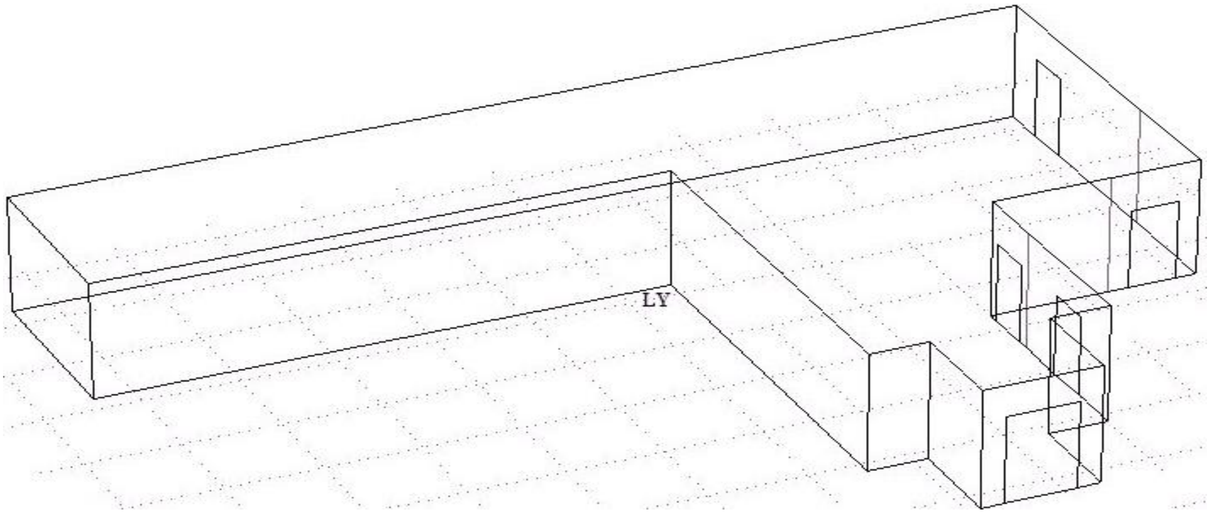


Figure 26: **Model of lobby**

BEDROOM1

It is composed of 8 surfaces including an exterior facing window and inside face door. A door is linked with the path way for an entry to the bedroom.

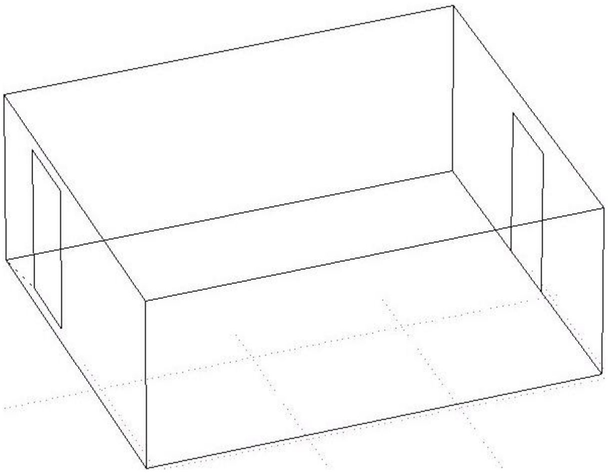


Figure 27: **Model of bedroom1**

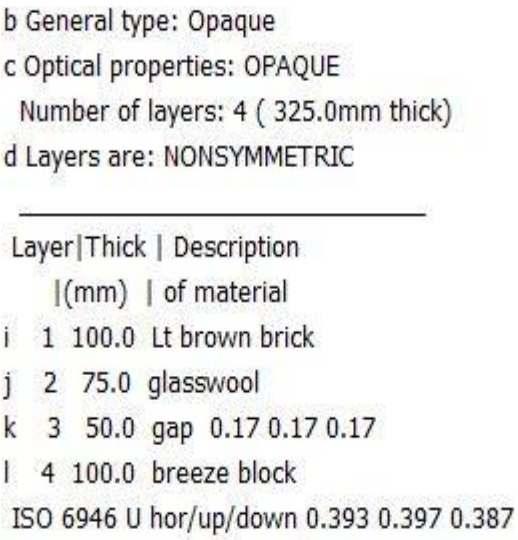
The volume and total surface area of the bedroom shown in the above figure27 is 69.4 m^3 and $28.9m^2$. The above dimensions are similar to bedroom 2-bedroom 7.

7.4 CONSTRUCTION MATERIALS

In the above geometry description, some wall surfaces of the zones are exposed directly to the outside environment. Hence this wall surfaces are assigned as external wall and other walls are referred as internal wall. The construction materials and its U-value differs for external wall, internal wall, ground, ceiling and ground of the upper floor.

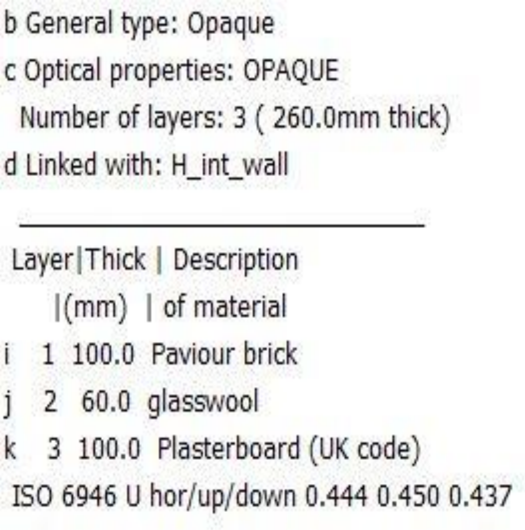
The following construction material and its U-values are assigned according to the information obtained from maintenance manager. Some of the materials exist in ESP-r database management facilities. The list of materials used for this model is shown below

EXTERNAL WALL



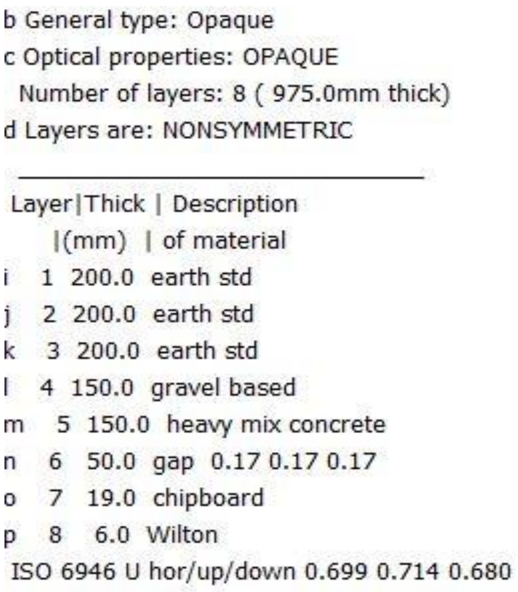
```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 4 ( 325.0mm thick)
d Layers are: NONSYMMETRIC
 ____________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1  100.0  Lt brown brick
j   2   75.0  glasswool
k   3   50.0  gap  0.17 0.17 0.17
l   4  100.0  breeze block
 ISO 6946 U hor/up/down 0.393 0.397 0.387
```

INTERNAL WALL



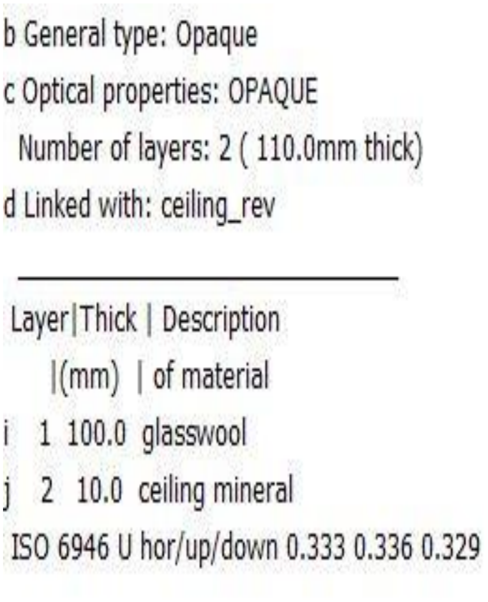
```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 3 ( 260.0mm thick)
d Linked with: H_int_wall
 ____________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1  100.0  Paviour brick
j   2   60.0  glasswool
k   3  100.0  Plasterboard (UK code)
 ISO 6946 U hor/up/down 0.444 0.450 0.437
```

GROUND



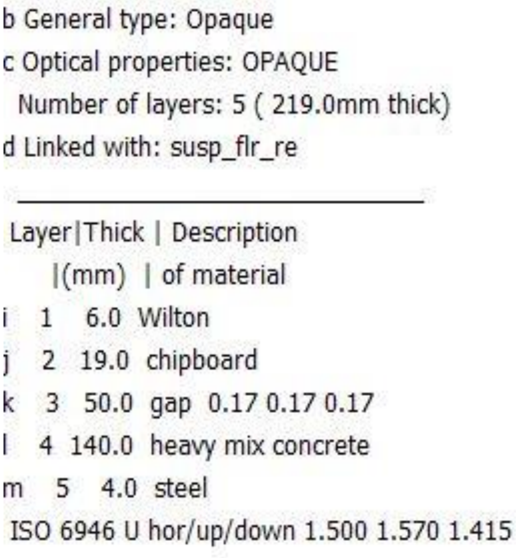
```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 8 ( 975.0mm thick)
d Layers are: NONSYMMETRIC
 ____________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1  200.0  earth std
j   2  200.0  earth std
k   3  200.0  earth std
l   4  150.0  gravel based
m   5  150.0  heavy mix concrete
n   6   50.0  gap  0.17 0.17 0.17
o   7   19.0  chipboard
p   8    6.0  Wilton
 ISO 6946 U hor/up/down 0.699 0.714 0.680
```

CEILING



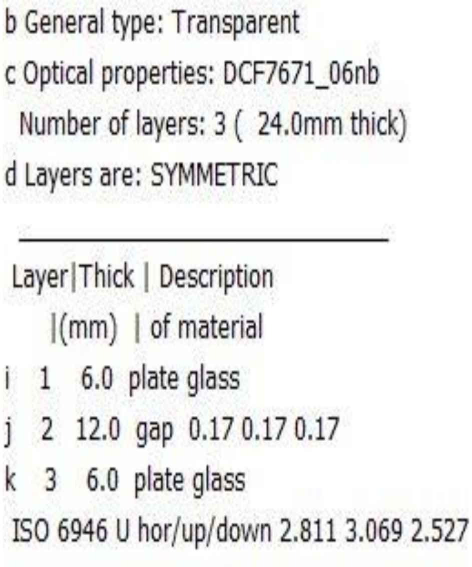
```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 2 ( 110.0mm thick)
d Linked with: ceiling_rev
 ____________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1  100.0  glasswool
j   2   10.0  ceiling mineral
 ISO 6946 U hor/up/down 0.333 0.336 0.329
```

SUSPENSION FLOOR



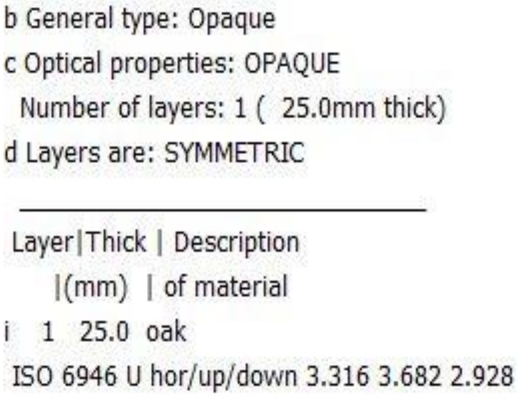
```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 5 ( 219.0mm thick)
d Linked with: susp_flr_re
 ___________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1    6.0  Wilton
j   2   19.0  chipboard
k   3   50.0  gap  0.17 0.17 0.17
l   4  140.0  heavy mix concrete
m   5    4.0  steel
 ISO 6946 U hor/up/down 1.500 1.570 1.415
```

DOUBLE GLAZING



```
b General type: Transparent
c Optical properties: DCF7671_06nb
  Number of layers: 3 (  24.0mm thick)
d Layers are: SYMMETRIC
 ___________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1    6.0  plate glass
j   2   12.0  gap  0.17 0.17 0.17
k   3    6.0  plate glass
 ISO 6946 U hor/up/down 2.811 3.069 2.527
```

DOOR

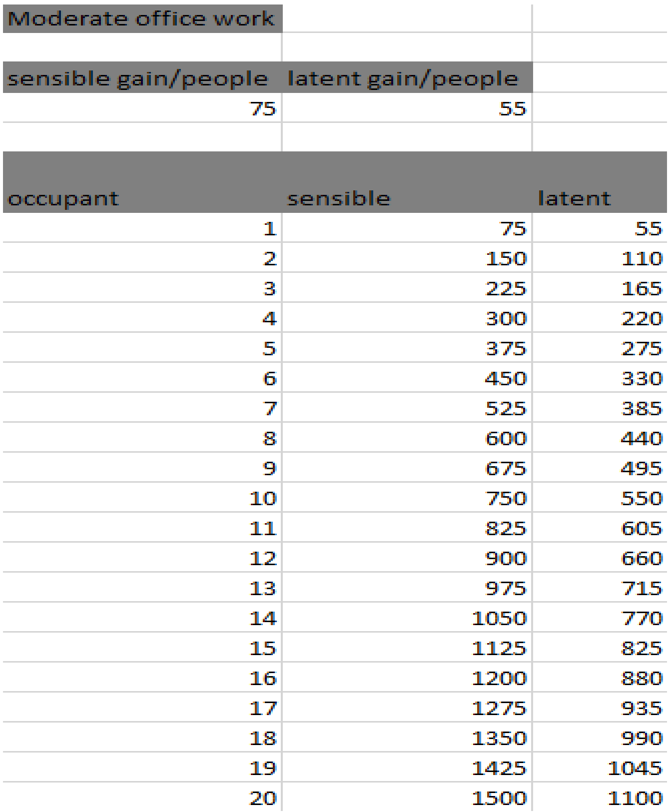


```
b General type: Opaque
c Optical properties: OPAQUE
  Number of layers: 1 (  25.0mm thick)
d Layers are: SYMMETRIC
 ___________________________
 Layer|Thick | Description
      |(mm)  | of material
i   1   25.0  oak
 ISO 6946 U hor/up/down 3.316 3.682 2.928
```

7.5 OPERATIONAL DETAILS

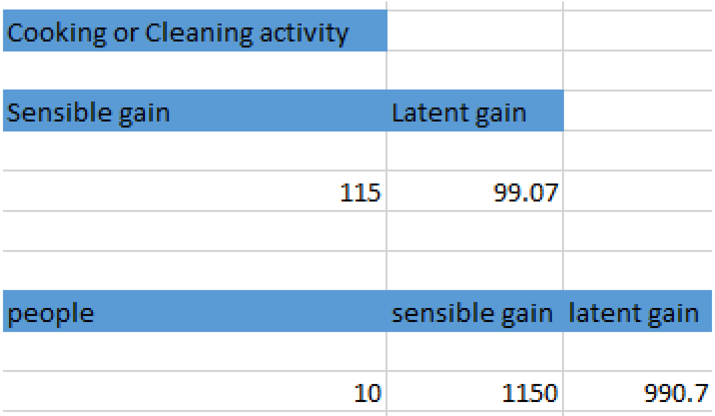
Since the information on occupancy and lighting fixtures for certain zones are not available, a new approach and assumptions have made to assign the sensible heat gain, latent heat gain, convection and radiation of occupant, light and equipment of the zones.

The following figure:28-31 represents the sensible and latent gain calculation performed in a spreadsheet for the people involved in moderate office work, cooking or cleaning activity and sleeping. Similarly the spreadsheet calculation is performed for sensible lighting gains.



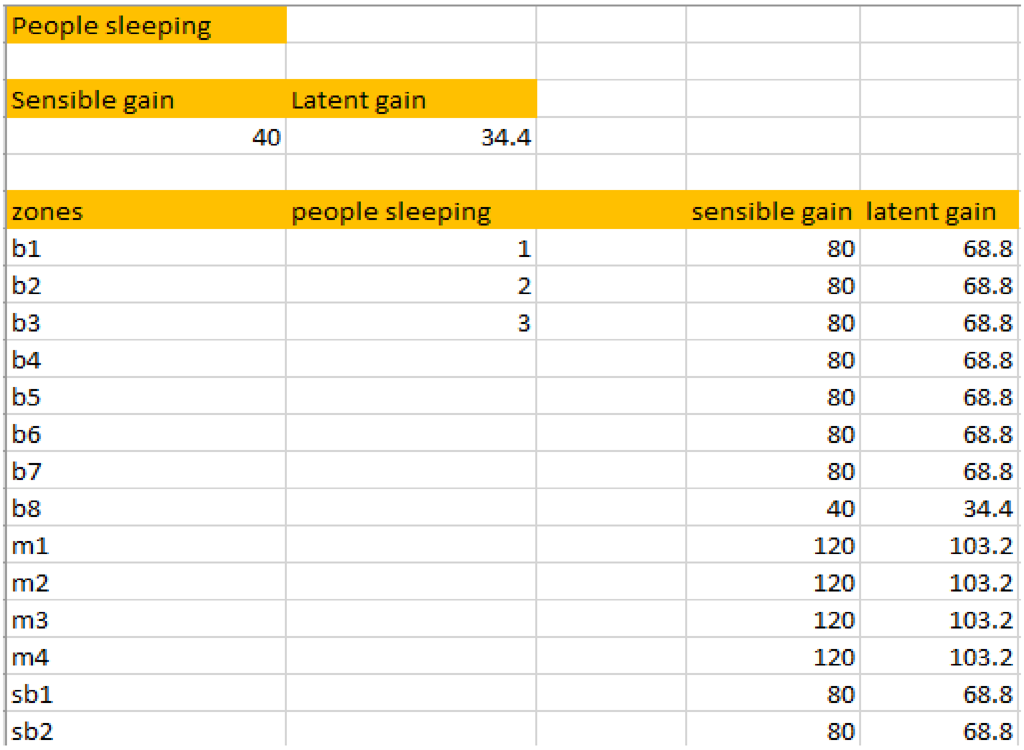
Moderate office work		
sensible gain/people	latent gain/people	
75	55	
occupant	sensible	latent
1	75	55
2	150	110
3	225	165
4	300	220
5	375	275
6	450	330
7	525	385
8	600	440
9	675	495
10	750	550
11	825	605
12	900	660
13	975	715
14	1050	770
15	1125	825
16	1200	880
17	1275	935
18	1350	990
19	1425	1045
20	1500	1100

Figure 28: **People doing moderate office work**



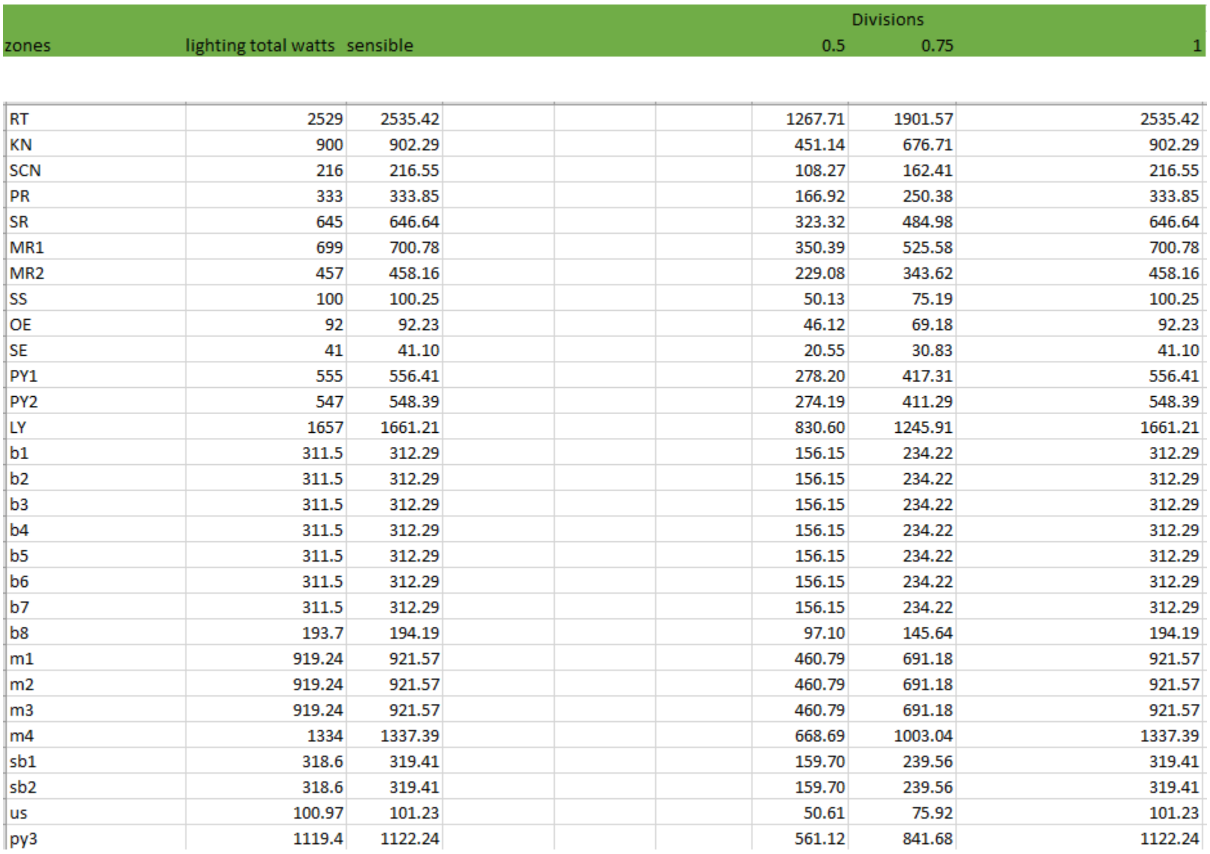
Cooking or Cleaning activity		
Sensible gain	Latent gain	
115	99.07	
people	sensible gain	latent gain
10	1150	990.7

Figure 29: **People involved in cooking or cleaning**



People sleeping				
Sensible gain	Latent gain			
40	34.4			
zones	people sleeping		sensible gain	latent gain
b1	1		80	68.8
b2	2		80	68.8
b3	3		80	68.8
b4			80	68.8
b5			80	68.8
b6			80	68.8
b7			80	68.8
b8			40	34.4
m1			120	103.2
m2			120	103.2
m3			120	103.2
m4			120	103.2
sb1			80	68.8
sb2			80	68.8

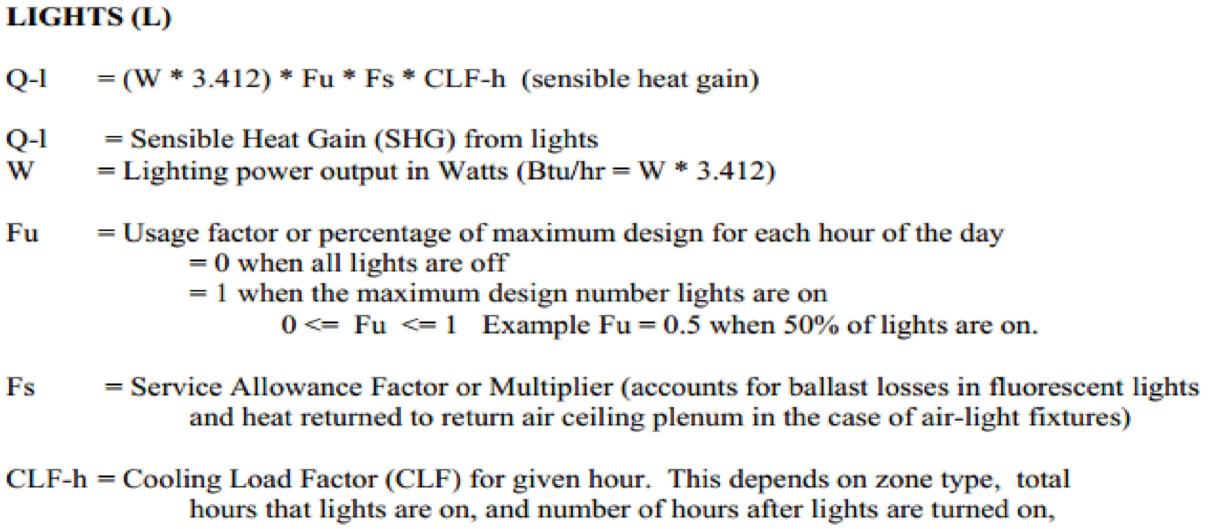
Figure 30: People sleeping



					Divisions		
zones	lighting total watts	sensible			0.5	0.75	1
RT	2529	2535.42			1267.71	1901.57	2535.42
KN	900	902.29			451.14	676.71	902.29
SCN	216	216.55			108.27	162.41	216.55
PR	333	333.85			166.92	250.38	333.85
SR	645	646.64			323.32	484.98	646.64
MR1	699	700.78			350.39	525.58	700.78
MR2	457	458.16			229.08	343.62	458.16
SS	100	100.25			50.13	75.19	100.25
OE	92	92.23			46.12	69.18	92.23
SE	41	41.10			20.55	30.83	41.10
PY1	555	556.41			278.20	417.31	556.41
PY2	547	548.39			274.19	411.29	548.39
LY	1657	1661.21			830.60	1245.91	1661.21
b1	311.5	312.29			156.15	234.22	312.29
b2	311.5	312.29			156.15	234.22	312.29
b3	311.5	312.29			156.15	234.22	312.29
b4	311.5	312.29			156.15	234.22	312.29
b5	311.5	312.29			156.15	234.22	312.29
b6	311.5	312.29			156.15	234.22	312.29
b7	311.5	312.29			156.15	234.22	312.29
b8	193.7	194.19			97.10	145.64	194.19
m1	919.24	921.57			460.79	691.18	921.57
m2	919.24	921.57			460.79	691.18	921.57
m3	919.24	921.57			460.79	691.18	921.57
m4	1334	1337.39			668.69	1003.04	1337.39
sb1	318.6	319.41			159.70	239.56	319.41
sb2	318.6	319.41			159.70	239.56	319.41
us	100.97	101.23			50.61	75.92	101.23
py3	1119.4	1122.24			561.12	841.68	1122.24

Figure 31: Sensible gain from lighting

The total watts selected for each zone is made by assuming 1W/ square feet. Later sensible gain is calculated by using the formula below:



LIGHTS (L)

Q-l = (W * 3.412) * Fu * Fs * CLF-h (sensible heat gain)

Q-l = Sensible Heat Gain (SHG) from lights
W = Lighting power output in Watts (Btu/hr = W * 3.412)

Fu = Usage factor or percentage of maximum design for each hour of the day
= 0 when all lights are off
= 1 when the maximum design number lights are on
0 <= Fu <= 1 Example Fu = 0.5 when 50% of lights are on.

Fs = Service Allowance Factor or Multiplier (accounts for ballast losses in fluorescent lights and heat returned to return air ceiling plenum in the case of air-light fixtures)

CLF-h = Cooling Load Factor (CLF) for given hour. This depends on zone type, total hours that lights are on, and number of hours after lights are turned on,

In the spread sheet calculation FU and CLF are not considered and FS for incandescent lamp is 1. Therefore the result obtained is converted in to watts by the following conversion 1 BTU/hr = 0.29307107 W.

RESTAURANT

Average people flow in the restaurant is assumed to be 50 in weekdays as well as in weekends from 9 to 24. The lighting for this zones is assigned to be 1270W from 9 to 24. Equipment used in a restaurant is a computer, so sensible gain appoint to be 110W. The graphical representation of casual gain is shown below

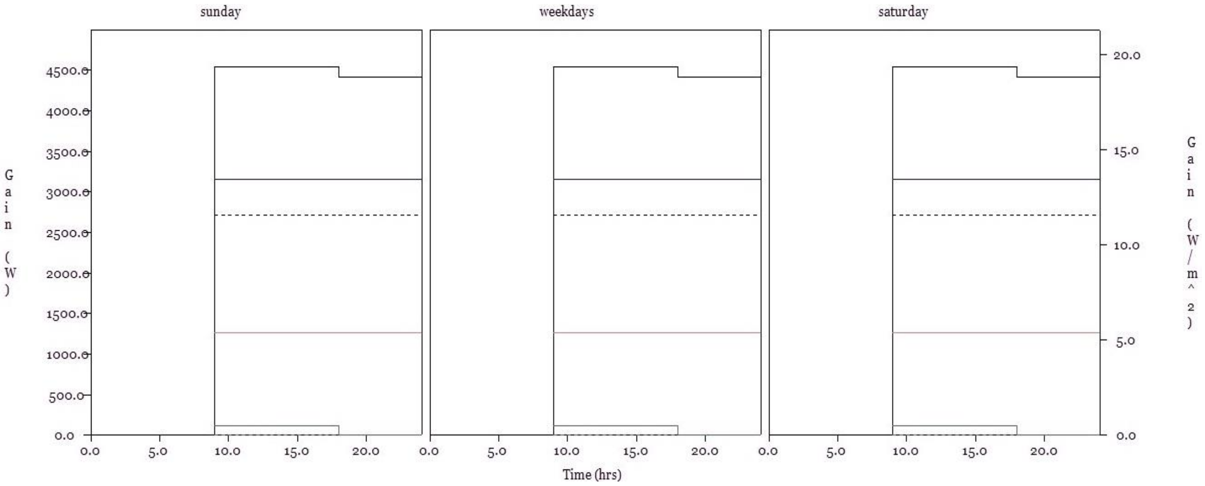


Figure 32: **Casual gain of restaurant**

KITCHEN

Number of people flow in the kitchen is assigned to be 10 in weekdays as well as in weekends from 10 to 24. The lighting for this zones is assigned to be 450W from 9 to 24. Several appliances has been used for cooking, heating, etc. So sensible gain appoint to be 1000W from 10 to 16 and 16 to 24 it is to be 1200. The graphical representation of casual gain is shown below

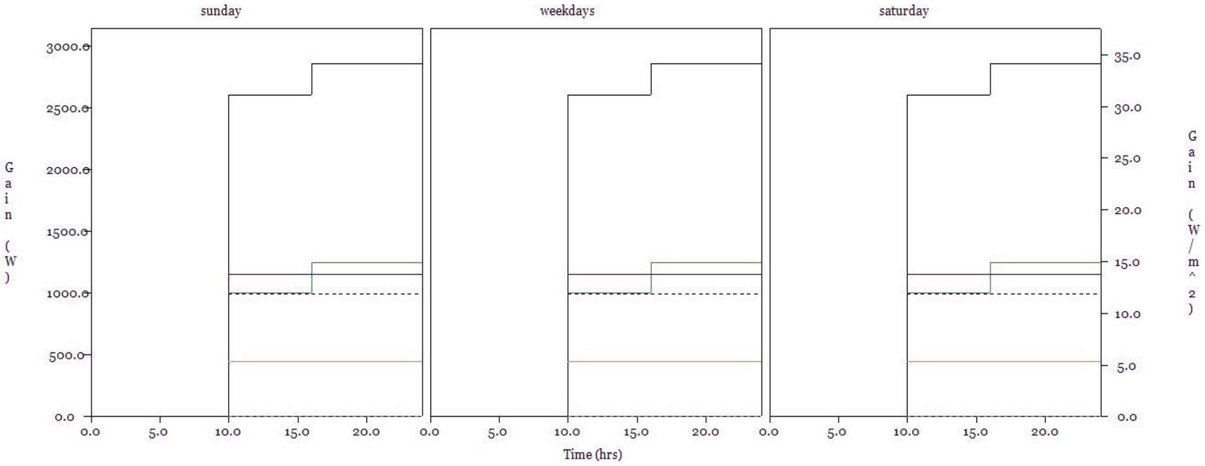


Figure 33: **Casual gain of kitchen**

OFFICE

Number of people in the restaurant is assumed to be 3 in all days from 9 to 12 and 14 to 18. The lighting for this zones is assigned to be 100W from 9 to 12 and 14 to 18. The graphical representation of casual gain is shown below

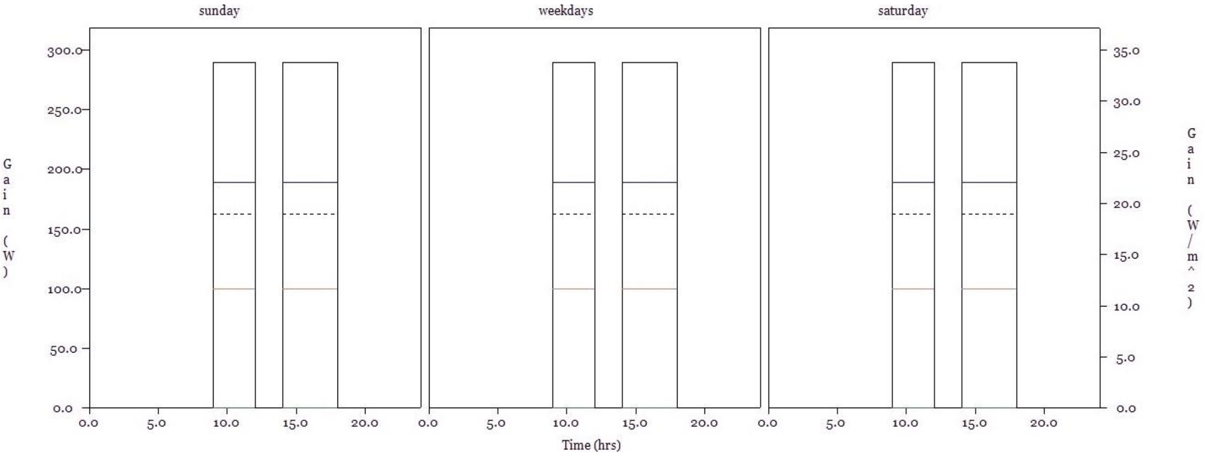


Figure 34: **Casual gain of office**

LOBBY

Number of people in the lobby is assumed to be 8 in all days from 9 to 18. The lighting for this zones is assigned to be 1250W from 9 to 18. Equipment used in a lobby is 5 computer, so sensible gain appoint to be 1010W. The graphical representation of casual gain is shown below

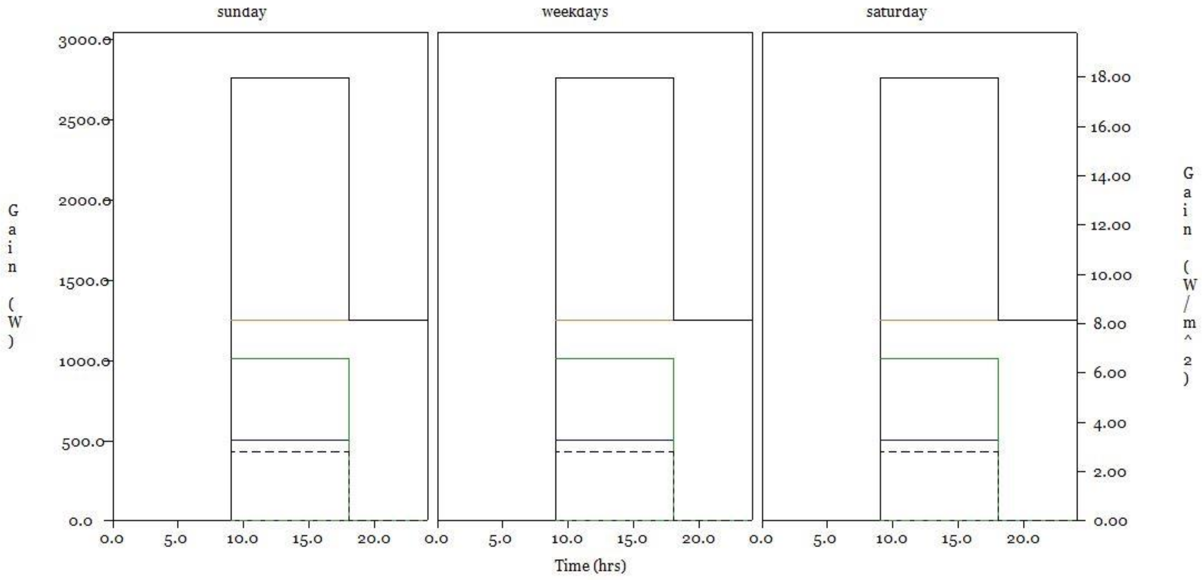


Figure 35: **Casual gain of lobby**

BEDROOM1

Number of people in the bedroom is assumed to be 2 in all days from 0 to 9 and 21 to 24. The lighting for this zones is assigned to be 310W from 21 to 24. The above operational details are similar to bedroom 2-bedroom 7. The graphical representation of casual gain is shown below

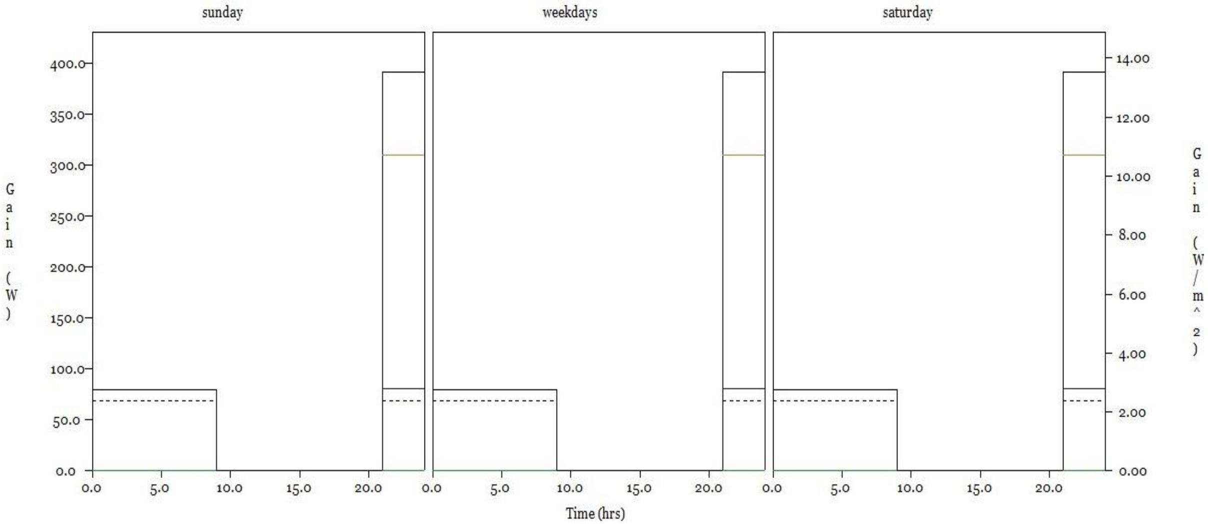


Figure 36: **Casual gain of bedroom1**

7.6 PLANT SYSTEM

Three MVHR systems are designed in order to improve the indoor air comfort and systems are named as system1, system2 and system3. System1 and 2 is installed at ground floor to control the temperature, humidity and indoor air comfort for winter and summer climate of the high occupancy zones like restaurant, kitchen, office and lobby. Likewise system3 is modelled for winter season and installed for the zones to control are: bedroom1, bedroom2, bedroom3 and bedroom4 in top floor.

Since the plant system do not exist in the hotel, the components selected for the design consist of duct, heat exchanger, heating coil, air mix box and centrifugal fan. The following figure37 represent the plant system model:

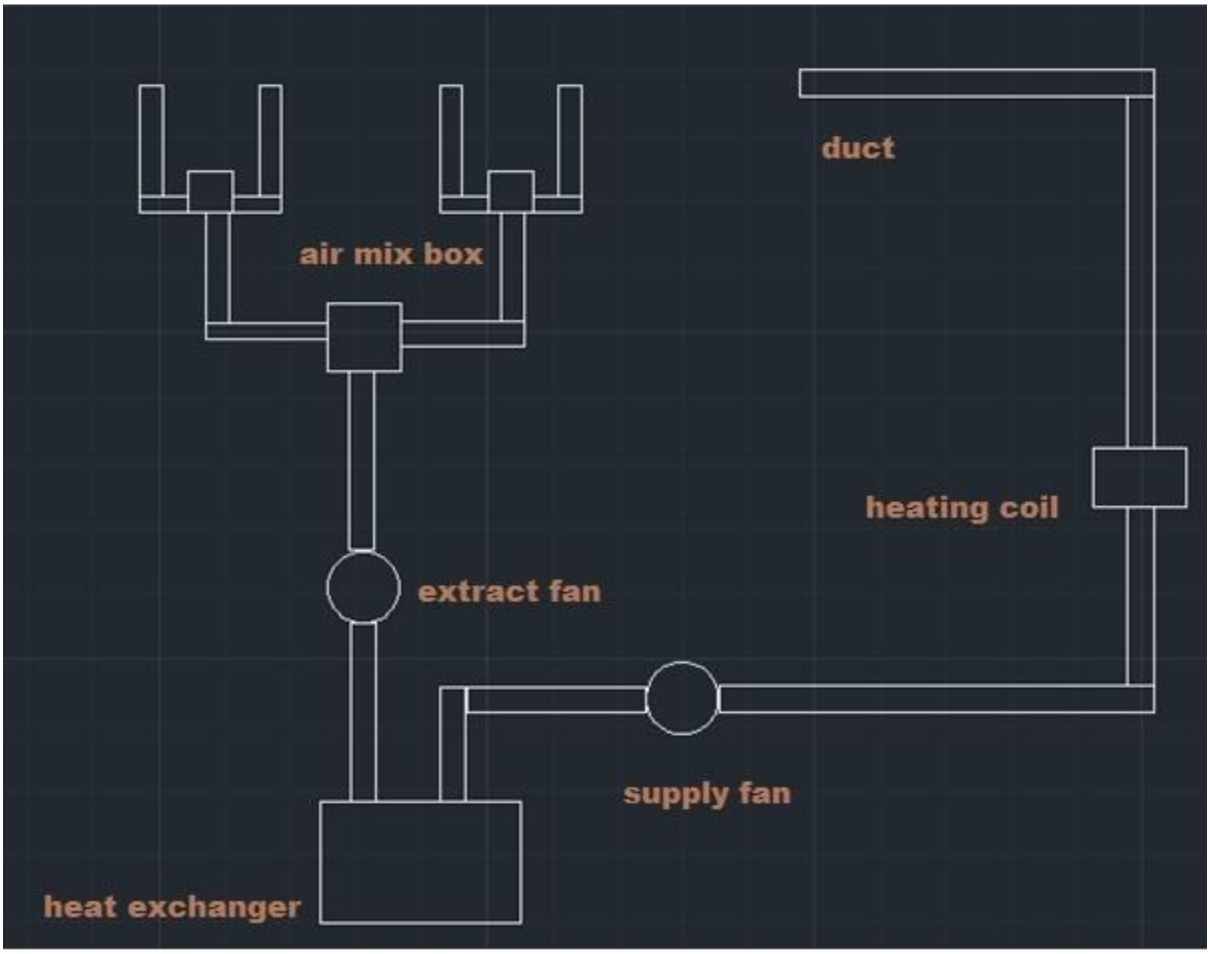


Figure 37: **Plant system model**

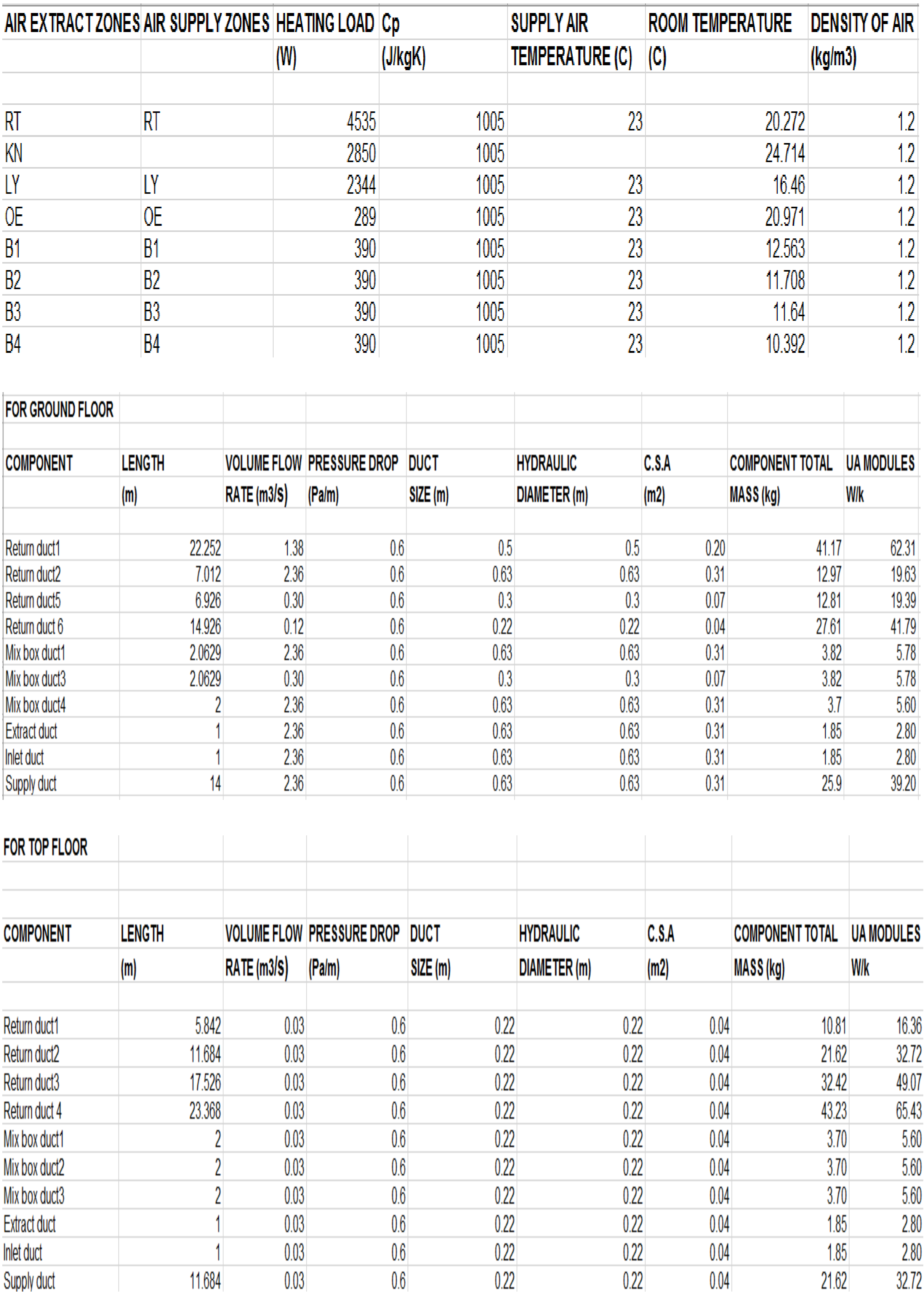
The design work involves various calculation to frame the proper system. For calculations, some parameter values are referred from the study of example MVHR models in ESP-r.

Some of them are listed below:

- Weight of the duct system-1.85 kg/m
- UA module is assumed to be 151.351% of the weight of the duct.

The pressure drop per unit length for hotel was chosen as 0.6 Pa/m. Circular duct is selected from the background study of duct system design for the plant. For circular duct, hydraulic diameter of the duct is equal to actual diameter of the duct. Formulas used for spreadsheet and calculation are shown below. The two system was designed to use in winter season to supply warm fresh air.

The figure38 represents the duct system parameter calculations for two floors.



AIR EXTRACT ZONES	AIR SUPPLY ZONES	HEATING LOAD (W)	Cp (J/kgK)	SUPPLY AIR TEMPERATURE (C)	ROOM TEMPERATURE (C)	DENSITY OF AIR (kg/m3)
RT	RT	4535	1005	23	20.272	1.2
KN		2850	1005		24.714	1.2
LY	LY	2344	1005	23	16.46	1.2
OE	OE	289	1005	23	20.971	1.2
B1	B1	390	1005	23	12.563	1.2
B2	B2	390	1005	23	11.708	1.2
B3	B3	390	1005	23	11.64	1.2
B4	B4	390	1005	23	10.392	1.2

FOR GROUND FLOOR

COMPONENT	LENGTH (m)	VOLUME FLOW RATE (m3/s)	PRESSURE DROP (Pa/m)	DUCT SIZE (m)	HYDRAULIC DIAMETER (m)	C.S.A (m2)	COMPONENT TOTAL MASS (kg)	UA MODULES W/k
Return duct1	22.252	1.38	0.6	0.5	0.5	0.20	41.17	62.31
Return duct2	7.012	2.36	0.6	0.63	0.63	0.31	12.97	19.63
Return duct5	6.926	0.30	0.6	0.3	0.3	0.07	12.81	19.39
Return duct 6	14.926	0.12	0.6	0.22	0.22	0.04	27.61	41.79
Mix box duct1	2.0629	2.36	0.6	0.63	0.63	0.31	3.82	5.78
Mix box duct3	2.0629	0.30	0.6	0.3	0.3	0.07	3.82	5.78
Mix box duct4	2	2.36	0.6	0.63	0.63	0.31	3.7	5.60
Extract duct	1	2.36	0.6	0.63	0.63	0.31	1.85	2.80
Inlet duct	1	2.36	0.6	0.63	0.63	0.31	1.85	2.80
Supply duct	14	2.36	0.6	0.63	0.63	0.31	25.9	39.20

FOR TOP FLOOR

COMPONENT	LENGTH (m)	VOLUME FLOW RATE (m3/s)	PRESSURE DROP (Pa/m)	DUCT SIZE (m)	HYDRAULIC DIAMETER (m)	C.S.A (m2)	COMPONENT TOTAL MASS (kg)	UA MODULES W/k
Return duct1	5.842	0.03	0.6	0.22	0.22	0.04	10.81	16.36
Return duct2	11.684	0.03	0.6	0.22	0.22	0.04	21.62	32.72
Return duct3	17.526	0.03	0.6	0.22	0.22	0.04	32.42	49.07
Return duct 4	23.368	0.03	0.6	0.22	0.22	0.04	43.23	65.43
Mix box duct1	2	0.03	0.6	0.22	0.22	0.04	3.70	5.60
Mix box duct2	2	0.03	0.6	0.22	0.22	0.04	3.70	5.60
Mix box duct3	2	0.03	0.6	0.22	0.22	0.04	3.70	5.60
Extract duct	1	0.03	0.6	0.22	0.22	0.04	1.85	2.80
Inlet duct	1	0.03	0.6	0.22	0.22	0.04	1.85	2.80
Supply duct	11.684	0.03	0.6	0.22	0.22	0.04	21.62	32.72

Figure 38: **Parameter calculations for duct system at ground and top floor**

Diameter of the duct system is calculated from the figure:39 relationship

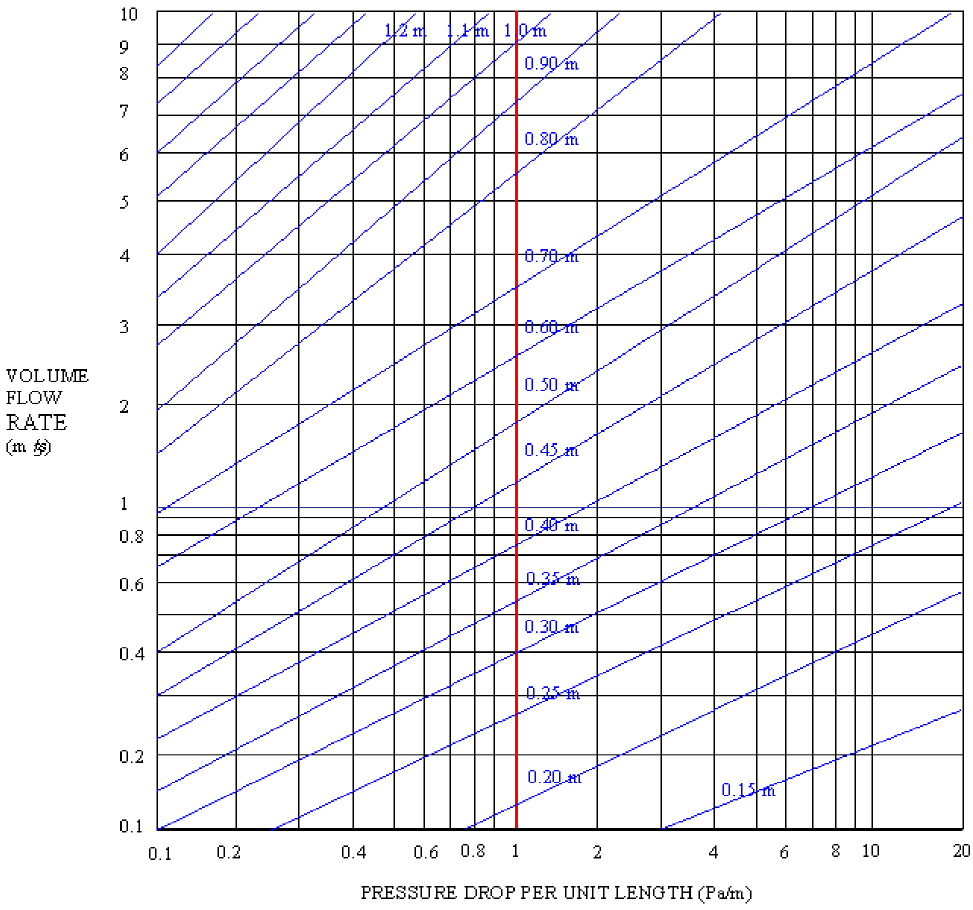
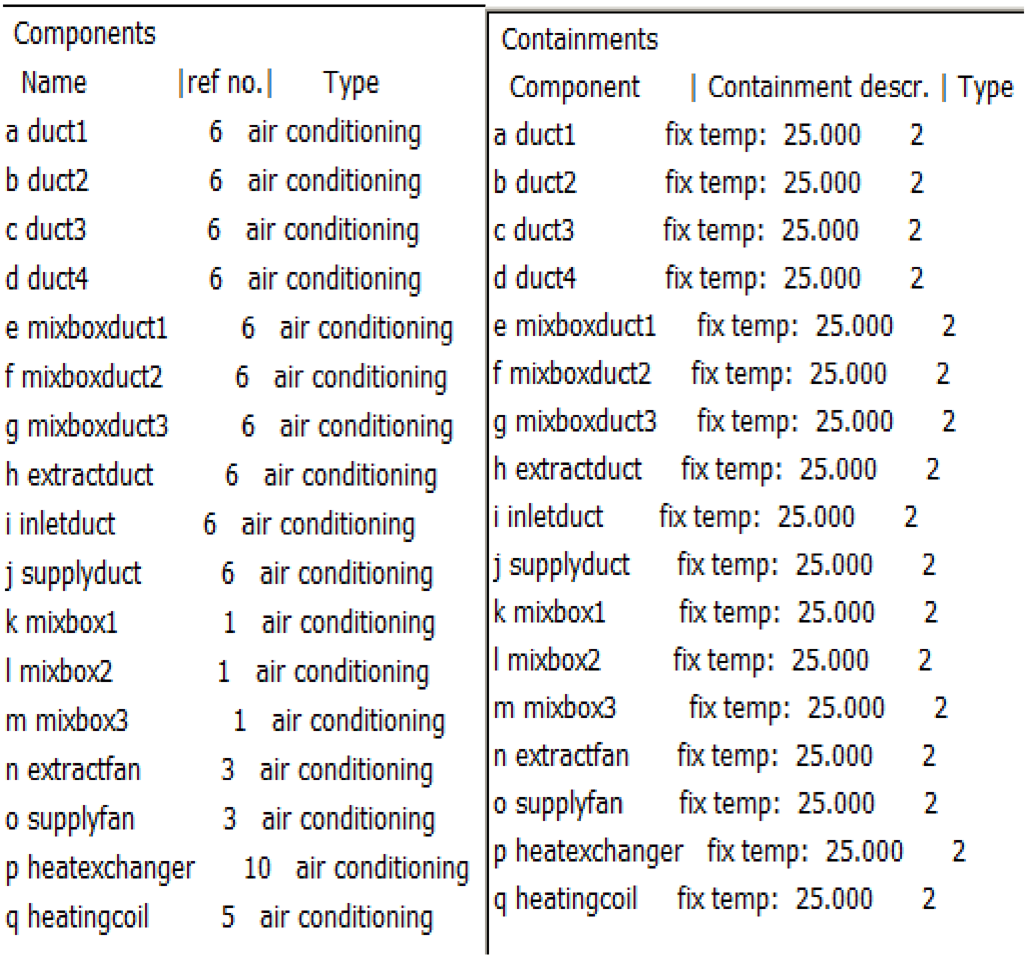


Figure 39: Volume flow rate VS Pressure drop

The figure 40, 41 and 42 will represent the components, connections, containments and plant linkage to the zones of the MVHR system. Here the components and containments are same for both the system but it differs only in connection and plant linkage to the zones.

System1 & System3



Components

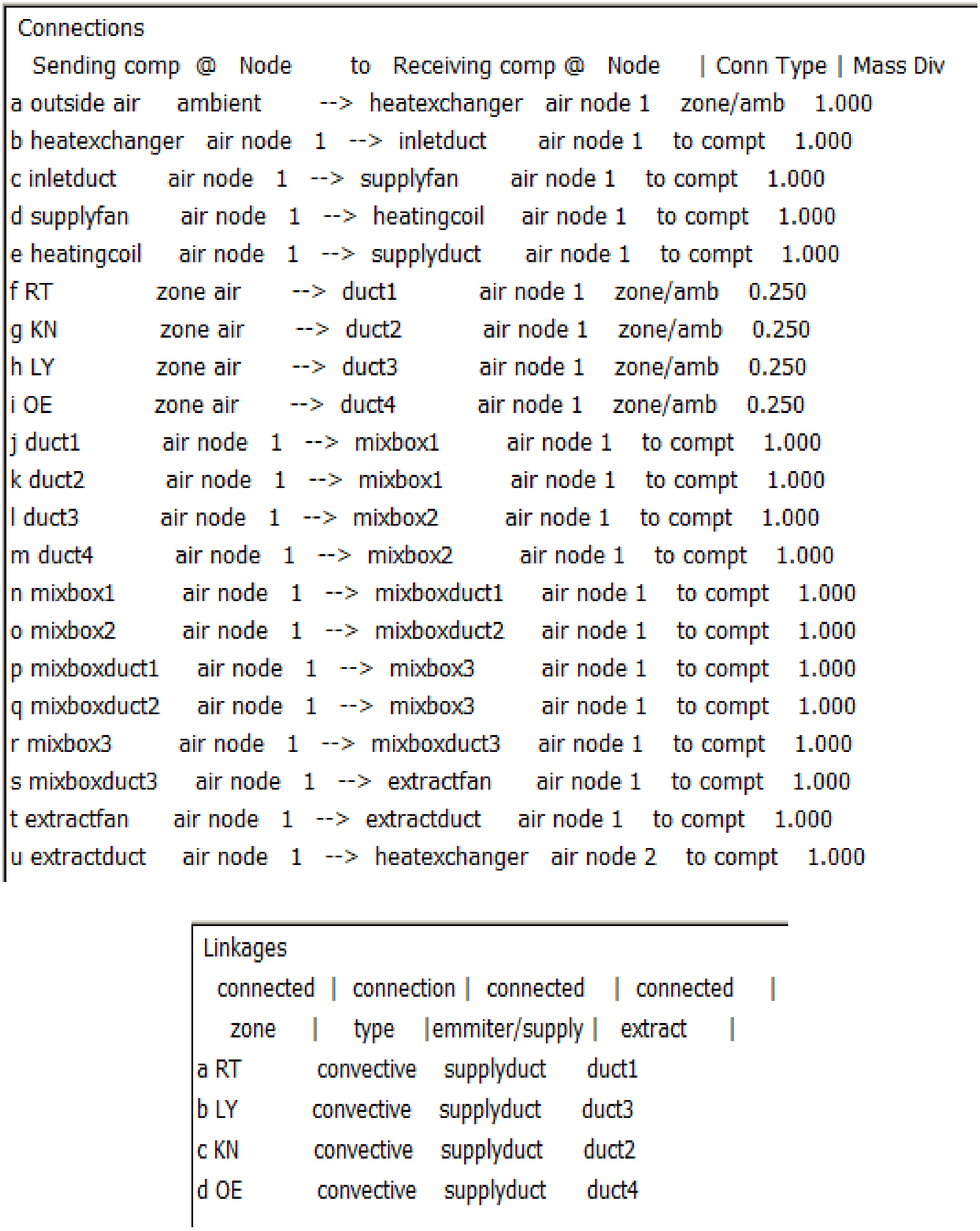
Name	ref no.	Type
a duct1	6	air conditioning
b duct2	6	air conditioning
c duct3	6	air conditioning
d duct4	6	air conditioning
e mixboxduct1	6	air conditioning
f mixboxduct2	6	air conditioning
g mixboxduct3	6	air conditioning
h extractduct	6	air conditioning
i inletduct	6	air conditioning
j supplyduct	6	air conditioning
k mixbox1	1	air conditioning
l mixbox2	1	air conditioning
m mixbox3	1	air conditioning
n extractfan	3	air conditioning
o supplyfan	3	air conditioning
p heatexchanger	10	air conditioning
q heatingcoil	5	air conditioning

Containments

Component	Containment descr.	Type
a duct1	fix temp: 25.000	2
b duct2	fix temp: 25.000	2
c duct3	fix temp: 25.000	2
d duct4	fix temp: 25.000	2
e mixboxduct1	fix temp: 25.000	2
f mixboxduct2	fix temp: 25.000	2
g mixboxduct3	fix temp: 25.000	2
h extractduct	fix temp: 25.000	2
i inletduct	fix temp: 25.000	2
j supplyduct	fix temp: 25.000	2
k mixbox1	fix temp: 25.000	2
l mixbox2	fix temp: 25.000	2
m mixbox3	fix temp: 25.000	2
n extractfan	fix temp: 25.000	2
o supplyfan	fix temp: 25.000	2
p heatexchanger	fix temp: 25.000	2
q heatingcoil	fix temp: 25.000	2

Figure 40: List of components and connections

System1

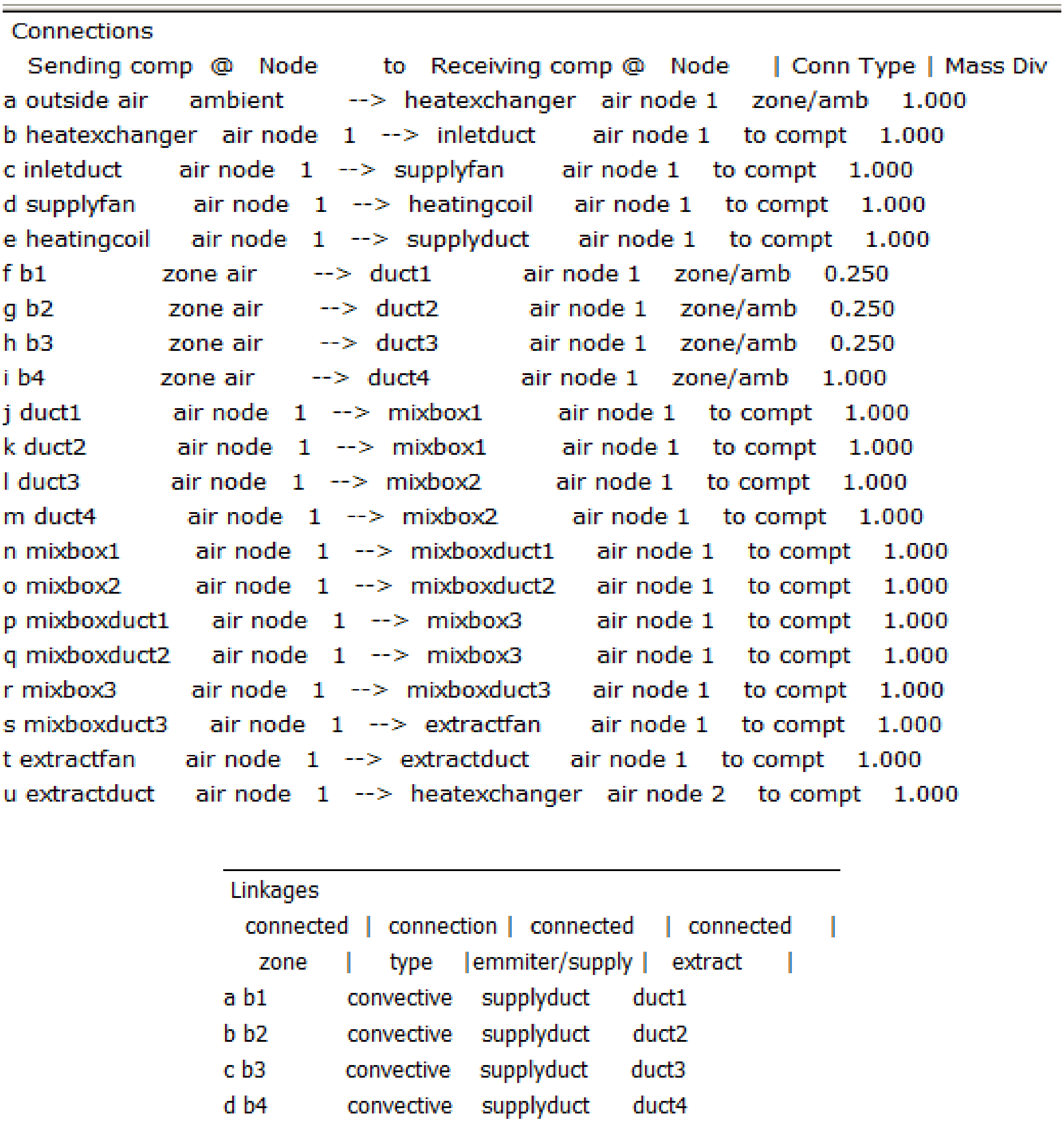


```
Connections
  Sending comp  @   Node       to   Receiving comp @   Node     | Conn Type | Mass Div
a outside air    ambient       -->  heatexchanger  air node 1   zone/amb    1.000
b heatexchanger  air node  1  -->  inletduct      air node 1   to compt    1.000
c inletduct      air node  1  -->  supplyfan      air node 1   to compt    1.000
d supplyfan      air node  1  -->  heatingcoil    air node 1   to compt    1.000
e heatingcoil    air node  1  -->  supplyduct     air node 1   to compt    1.000
f RT             zone air     -->  duct1          air node 1   zone/amb    0.250
g KN             zone air     -->  duct2          air node 1   zone/amb    0.250
h LY             zone air     -->  duct3          air node 1   zone/amb    0.250
i OE             zone air     -->  duct4          air node 1   zone/amb    0.250
j duct1          air node  1  -->  mixbox1        air node 1   to compt    1.000
k duct2          air node  1  -->  mixbox1        air node 1   to compt    1.000
l duct3          air node  1  -->  mixbox2        air node 1   to compt    1.000
m duct4          air node  1  -->  mixbox2        air node 1   to compt    1.000
n mixbox1        air node  1  -->  mixboxduct1    air node 1   to compt    1.000
o mixbox2        air node  1  -->  mixboxduct2    air node 1   to compt    1.000
p mixboxduct1    air node  1  -->  mixbox3        air node 1   to compt    1.000
q mixboxduct2    air node  1  -->  mixbox3        air node 1   to compt    1.000
r mixbox3        air node  1  -->  mixboxduct3    air node 1   to compt    1.000
s mixboxduct3    air node  1  -->  extractfan     air node 1   to compt    1.000
t extractfan     air node  1  -->  extractduct    air node 1   to compt    1.000
u extractduct    air node  1  -->  heatexchanger  air node 2   to compt    1.000
```

```
Linkages
  connected  |  connection |  connected     |  connected    |
    zone     |     type    |emmiter/supply  |  extract      |
a RT          convective    supplyduct       duct1
b LY          convective    supplyduct       duct3
c KN          convective    supplyduct       duct2
d OE          convective    supplyduct       duct4
```

Figure 41: Connection of components and plant linkage to zones

System3

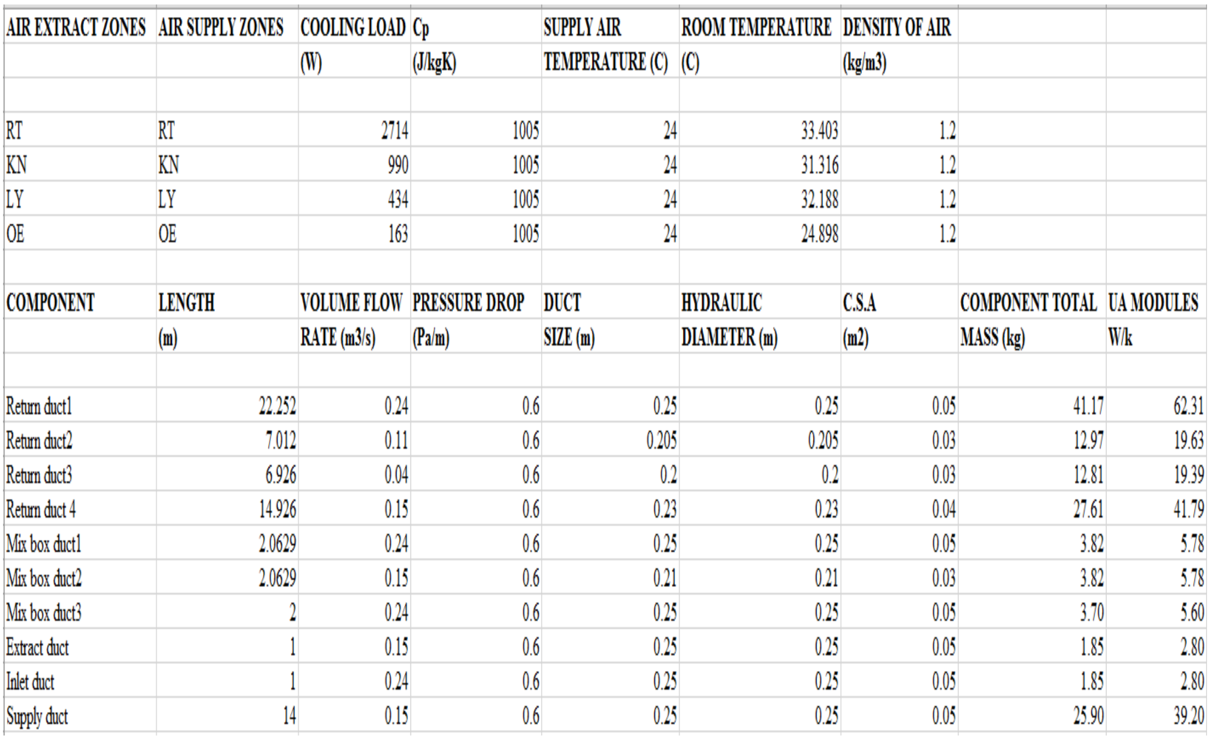


```
Connections
  Sending comp  @   Node       to   Receiving comp @   Node      | Conn Type | Mass Div
a outside air     ambient      -->  heatexchanger  air node 1   zone/amb    1.000
b heatexchanger   air node  1  -->  inletduct      air node 1   to compt    1.000
c inletduct       air node  1  -->  supplyfan      air node 1   to compt    1.000
d supplyfan       air node  1  -->  heatingcoil    air node 1   to compt    1.000
e heatingcoil     air node  1  -->  supplyduct     air node 1   to compt    1.000
f b1              zone air     -->  duct1          air node 1   zone/amb    0.250
g b2              zone air     -->  duct2          air node 1   zone/amb    0.250
h b3              zone air     -->  duct3          air node 1   zone/amb    0.250
i b4              zone air     -->  duct4          air node 1   zone/amb    1.000
j duct1           air node  1  -->  mixbox1        air node 1   to compt    1.000
k duct2           air node  1  -->  mixbox1        air node 1   to compt    1.000
l duct3           air node  1  -->  mixbox2        air node 1   to compt    1.000
m duct4           air node  1  -->  mixbox2        air node 1   to compt    1.000
n mixbox1         air node  1  -->  mixboxduct1    air node 1   to compt    1.000
o mixbox2         air node  1  -->  mixboxduct2    air node 1   to compt    1.000
p mixboxduct1     air node  1  -->  mixbox3        air node 1   to compt    1.000
q mixboxduct2     air node  1  -->  mixbox3        air node 1   to compt    1.000
r mixbox3         air node  1  -->  mixboxduct3    air node 1   to compt    1.000
s mixboxduct3     air node  1  -->  extractfan     air node 1   to compt    1.000
t extractfan      air node  1  -->  extractduct    air node 1   to compt    1.000
u extractduct     air node  1  -->  heatexchanger  air node 2   to compt    1.000
```

```
Linkages
  connected  |  connection |  connected     |  connected    |
    zone     |     type    |emmiter/supply |  extract      |
a b1           convective    supplyduct       duct1
b b2           convective    supplyduct       duct2
c b3           convective    supplyduct       duct3
d b4           convective    supplyduct       duct4
```

Figure 42: Connection of components and plant linkage to zones

If there is a no summer bypass mode the temperature of the zone will increase drastically and cause discomfort. In the modelling a new method has been analysed to introduce a fresh cool air to the zones in summer. This method was accomplished by replacing heating coil with cooling coil and connected to ground floor zones. For cooling system- length, total mass and UA modules of the duct remains same as heating system. Beside it is necessary to calculate the volume flow rate, duct diameter and cross sectional area. The figure: 43 represents the duct for cooling system calculations



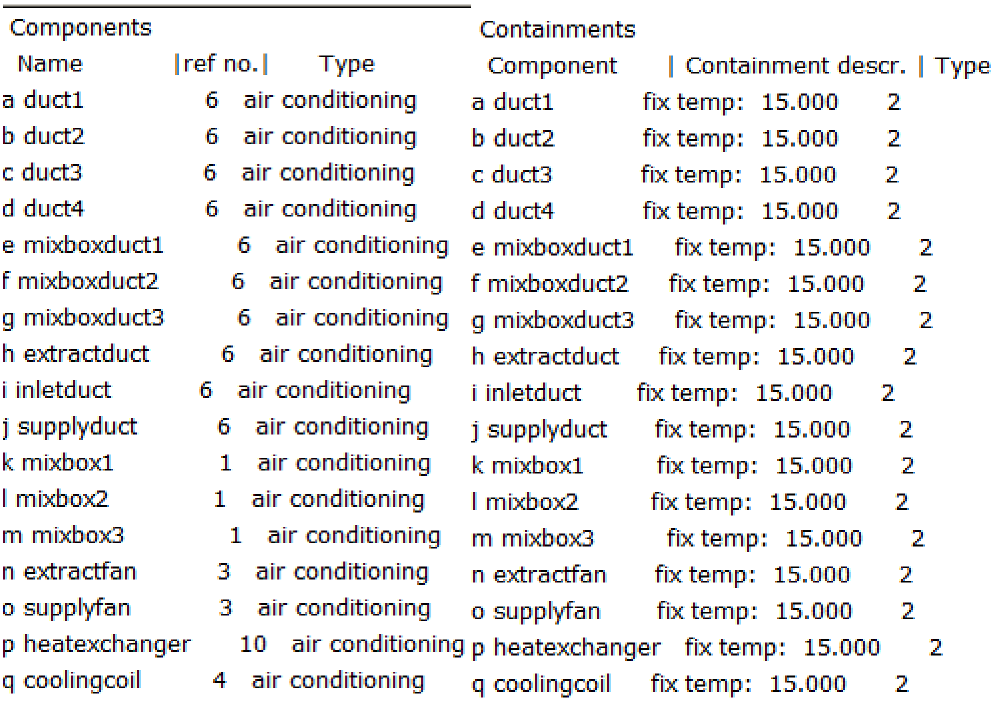
AIR EXTRACT ZONES	AIR SUPPLY ZONES	COOLING LOAD (W)	Cp (J/kgK)	SUPPLY AIR TEMPERATURE (C)	ROOM TEMPERATURE (C)	DENSITY OF AIR (kg/m3)
RT	RT	2714	1005	24	33.403	1.2
KN	KN	990	1005	24	31.316	1.2
LY	LY	434	1005	24	32.188	1.2
OE	OE	163	1005	24	24.898	1.2

COMPONENT	LENGTH (m)	VOLUME FLOW RATE (m3/s)	PRESSURE DROP (Pa/m)	DUCT SIZE (m)	HYDRAULIC DIAMETER (m)	C.S.A (m2)	COMPONENT TOTAL MASS (kg)	UA MODULES W/k
Return duct1	22.252	0.24	0.6	0.25	0.25	0.05	41.17	62.31
Return duct2	7.012	0.11	0.6	0.205	0.205	0.03	12.97	19.63
Return duct3	6.926	0.04	0.6	0.2	0.2	0.03	12.81	19.39
Return duct 4	14.926	0.15	0.6	0.23	0.23	0.04	27.61	41.79
Mix box duct1	2.0629	0.24	0.6	0.25	0.25	0.05	3.82	5.78
Mix box duct2	2.0629	0.15	0.6	0.21	0.21	0.03	3.82	5.78
Mix box duct3	2	0.24	0.6	0.25	0.25	0.05	3.70	5.60
Extract duct	1	0.15	0.6	0.25	0.25	0.05	1.85	2.80
Inlet duct	1	0.24	0.6	0.25	0.25	0.05	1.85	2.80
Supply duct	14	0.15	0.6	0.25	0.25	0.05	25.90	39.20

Figure 43: Parameter calculations for duct system at ground floor

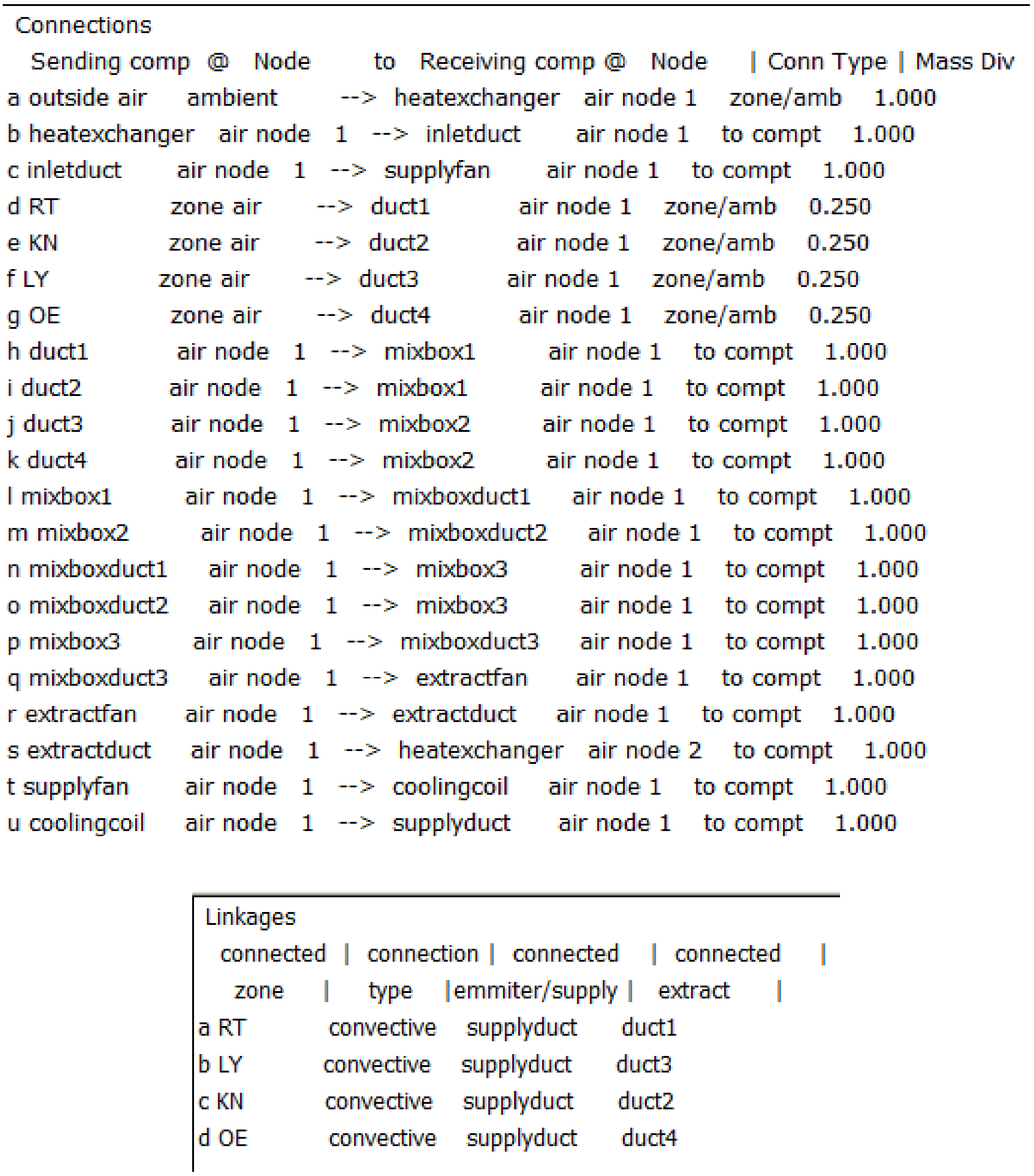
The figure: 44 and 45 represent the components, connections, containments and plant linkage to the zones of the MVHR system.

System2



```
Components                                   Containments
 Name         |ref no.|    Type               Component    | Containment descr. | Type
a duct1           6   air conditioning       a duct1        fix temp:  15.000     2
b duct2           6   air conditioning       b duct2        fix temp:  15.000     2
c duct3           6   air conditioning       c duct3        fix temp:  15.000     2
d duct4           6   air conditioning       d duct4        fix temp:  15.000     2
e mixboxduct1        6   air conditioning    e mixboxduct1     fix temp:  15.000     2
f mixboxduct2        6   air conditioning    f mixboxduct2     fix temp:  15.000     2
g mixboxduct3        6   air conditioning    g mixboxduct3     fix temp:  15.000     2
h extractduct       6   air conditioning     h extractduct    fix temp:  15.000     2
i inletduct       6   air conditioning       i inletduct     fix temp:  15.000     2
j supplyduct       6   air conditioning      j supplyduct     fix temp:  15.000     2
k mixbox1          1   air conditioning      k mixbox1        fix temp:  15.000     2
l mixbox2         1   air conditioning       l mixbox2       fix temp:  15.000     2
m mixbox3           1   air conditioning     m mixbox3         fix temp:  15.000     2
n extractfan       3   air conditioning      n extractfan     fix temp:  15.000     2
o supplyfan        3   air conditioning      o supplyfan      fix temp:  15.000     2
p heatexchanger      10   air conditioning p heatexchanger   fix temp:  15.000     2
q coolingcoil      4   air conditioning      q coolingcoil    fix temp:  15.000     2
```

Figure 44: List of components and connections



```
Connections
  Sending comp  @   Node       to   Receiving comp @   Node     | Conn Type | Mass Div
a outside air     ambient       -->  heatexchanger   air node 1   zone/amb    1.000
b heatexchanger  air node  1   -->  inletduct       air node 1   to compt    1.000
c inletduct      air node  1   -->  supplyfan       air node 1   to compt    1.000
d RT             zone air      -->  duct1           air node 1   zone/amb    0.250
e KN             zone air      -->  duct2           air node 1   zone/amb    0.250
f LY             zone air      -->  duct3           air node 1   zone/amb    0.250
g OE             zone air      -->  duct4           air node 1   zone/amb    0.250
h duct1          air node  1   -->  mixbox1         air node 1   to compt    1.000
i duct2          air node  1   -->  mixbox1         air node 1   to compt    1.000
j duct3          air node  1   -->  mixbox2         air node 1   to compt    1.000
k duct4          air node  1   -->  mixbox2         air node 1   to compt    1.000
l mixbox1        air node  1   -->  mixboxduct1     air node 1   to compt    1.000
m mixbox2        air node  1   -->  mixboxduct2     air node 1   to compt    1.000
n mixboxduct1    air node  1   -->  mixbox3         air node 1   to compt    1.000
o mixboxduct2    air node  1   -->  mixbox3         air node 1   to compt    1.000
p mixbox3        air node  1   -->  mixboxduct3     air node 1   to compt    1.000
q mixboxduct3    air node  1   -->  extractfan      air node 1   to compt    1.000
r extractfan     air node  1   -->  extractduct     air node 1   to compt    1.000
s extractduct    air node  1   -->  heatexchanger   air node 2   to compt    1.000
t supplyfan      air node  1   -->  coolingcoil     air node 1   to compt    1.000
u coolingcoil    air node  1   -->  supplyduct      air node 1   to compt    1.000
```

```
Linkages
  connected  |  connection |  connected     |  connected    |
    zone     |     type    |emmiter/supply |   extract     |
a RT            convective    supplyduct      duct1
b LY            convective    supplyduct      duct3
c KN            convective    supplyduct      duct2
d OE            convective    supplyduct      duct4
```

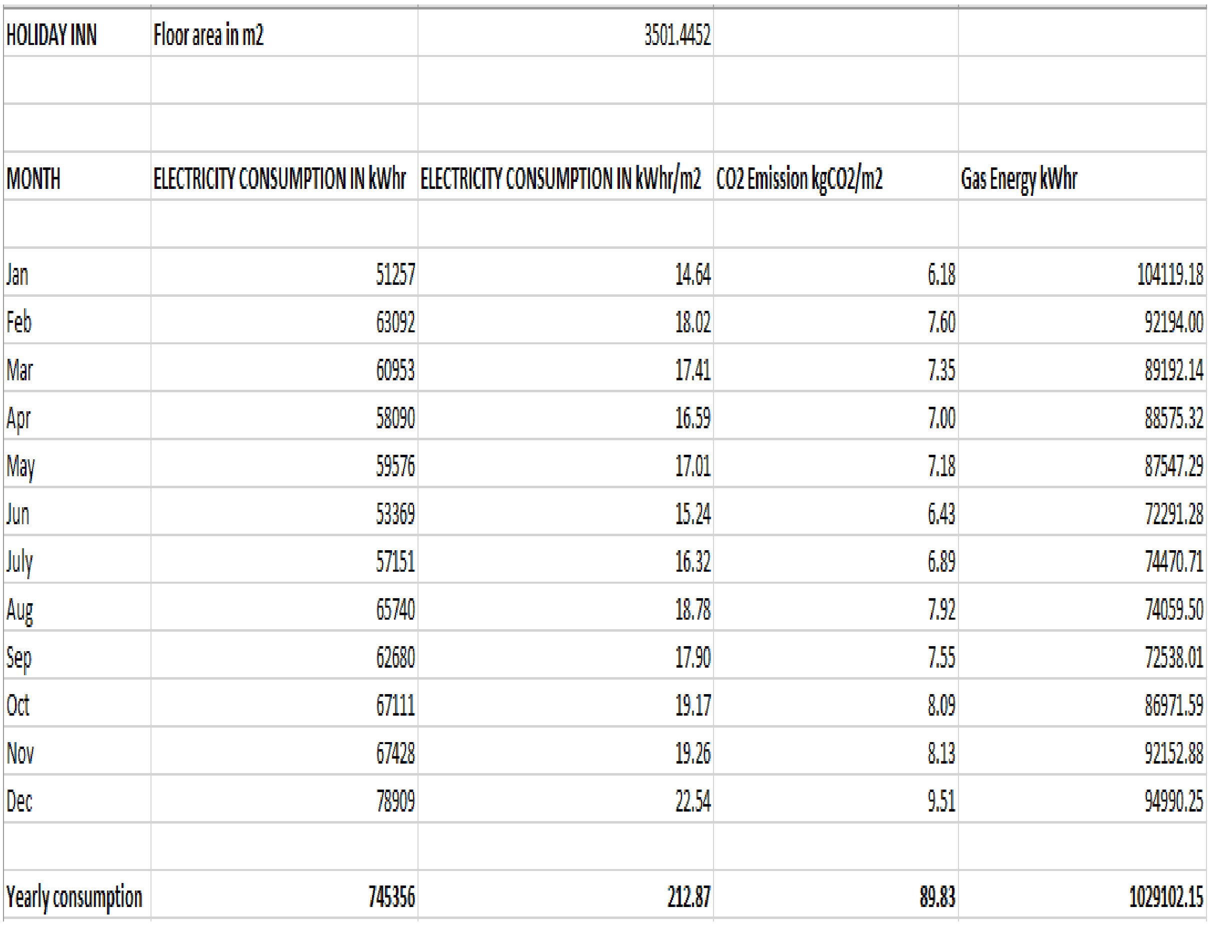
Figure 45: Connection of components and plant linkage to zones

8 ENERGY PERFORMANCE ANALYSIS

Energy performance of the building is determined by calculating the electricity consumption in kWhr/m^2 over each month as shown in the figure: 46 is calculated by dividing electricity consumption in kWhr by total floor area of the hotel. Likewise CO_2 emission is calculated by multiplying electricity consumption in kWhr/m^2 with the conversion factor of 0.422

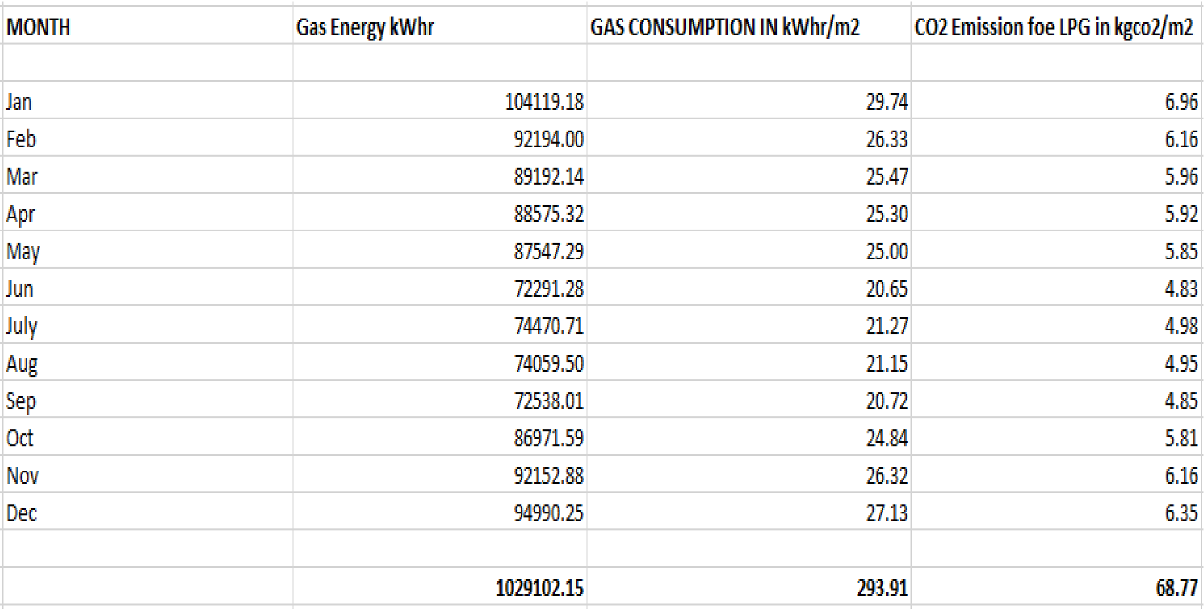
Similarly the gas consumption in kWhr/m^2 over each month shown in the figure: 47 is calculated by dividing gas consumption in kWhr by total floor area of the hotel. Likewise CO_2 emission is calculated by multiplying gas consumption in kWhr/m^2 with the following conversion factor

- CO_2 conversion factor for natural gas is 0.194
- CO_2 conversion factor for liquefied petroleum gas is 0.234



HOLIDAY INN	Floor area in m2	3501.4452		
MONTH	ELECTRICITY CONSUMPTION IN kWhr	ELECTRICITY CONSUMPTION IN kWhr/m2	CO2 Emission kgCO2/m2	Gas Energy kWhr
Jan	51257	14.64	6.18	104119.18
Feb	63092	18.02	7.60	92194.00
Mar	60953	17.41	7.35	89192.14
Apr	58090	16.59	7.00	88575.32
May	59576	17.01	7.18	87547.29
Jun	53369	15.24	6.43	72291.28
July	57151	16.32	6.89	74470.71
Aug	65740	18.78	7.92	74059.50
Sep	62680	17.90	7.55	72538.01
Oct	67111	19.17	8.09	86971.59
Nov	67428	19.26	8.13	92152.88
Dec	78909	22.54	9.51	94990.25
Yearly consumption	**745356**	**212.87**	**89.83**	**1029102.15**

Figure 46: Electricity consumption of the building



MONTH	Gas Energy kWhr	GAS CONSUMPTION IN kWhr/m2	CO2 Emission foe LPG in kgco2/m2
Jan	104119.18	29.74	6.96
Feb	92194.00	26.33	6.16
Mar	89192.14	25.47	5.96
Apr	88575.32	25.30	5.92
May	87547.29	25.00	5.85
Jun	72291.28	20.65	4.83
July	74470.71	21.27	4.98
Aug	74059.50	21.15	4.95
Sep	72538.01	20.72	4.85
Oct	86971.59	24.84	5.81
Nov	92152.88	26.32	6.16
Dec	94990.25	27.13	6.35
	1029102.15	**293.91**	**68.77**

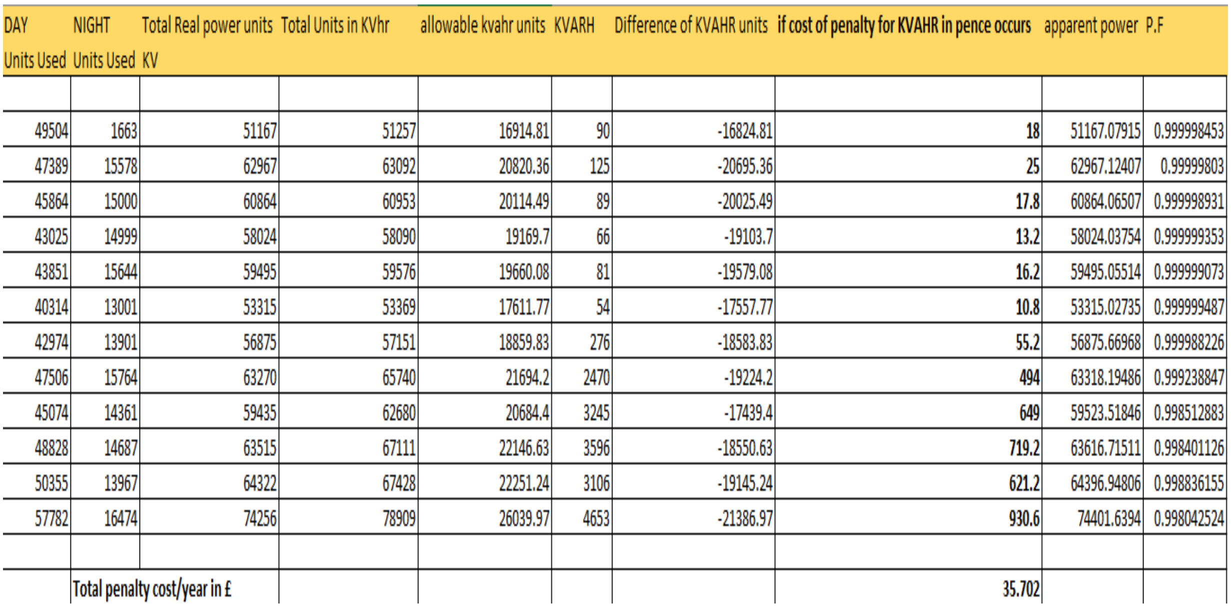
Figure 47: Gas consumption of the building

The annual kWhr/m^2 consumption and CO_2 emission of both electric and gas is compared with the CIBSE TM: 46 (2008). The table: 2 represents the benchmark for hotel

S.no	Name	Electricity typical benchmark kWhr/m^2	Fossil thermal typical benchmark kWhr/m^2	Electricity typical benchmark kgCO_2/m^2	Fossil thermal typical benchmark kgCO_2/m^2	Total typical benchmark kgCO_2/m^2
1	Hotel	105	330	57.8	62.7	120.5

Table 2: Energy benchmark

The effective utilization of power, was found by measuring the reactive power consumptions. The spread sheet calculations involved is shown in the figure: 48.



DAY Units Used	NIGHT Units Used	Total Real power units KV	Total Units in KVhr	allowable kvahr units	KVARH	Difference of KVAHR units	**if cost of penalty for KVAHR in pence occurs**	apparent power	P.F
49504	1663	51167	51257	16914.81	90	-16824.81	**18**	51167.07915	0.999998453
47389	15578	62967	63092	20820.36	125	-20695.36	**25**	62967.12407	0.99999803
45864	15000	60864	60953	20114.49	89	-20025.49	**17.8**	60864.06507	0.999998931
43025	14999	58024	58090	19169.7	66	-19103.7	**13.2**	58024.03754	0.999999353
43851	15644	59495	59576	19660.08	81	-19579.08	**16.2**	59495.05514	0.999999073
40314	13001	53315	53369	17611.77	54	-17557.77	**10.8**	53315.02735	0.999999487
42974	13901	56875	57151	18859.83	276	-18583.83	**55.2**	56875.66968	0.999988226
47506	15764	63270	65740	21694.2	2470	-19224.2	**494**	63318.19486	0.999238847
45074	14361	59435	62680	20684.4	3245	-17439.4	**649**	59523.51846	0.998512883
48828	14687	63515	67111	22146.63	3596	-18550.63	**719.2**	63616.71511	0.998401126
50355	13967	64322	67428	22251.24	3106	-19145.24	**621.2**	64396.94806	0.998836155
57782	16474	74256	78909	26039.97	4653	-21386.97	**930.6**	74401.6394	0.998042524
	Total penalty cost/year in £						35.702		

Figure 48: Electrical power calculations

Total units in kWhr is the sum of real and reactive power. The allowable reactive power consumption for commercial sector is 30% of total units. Power factor should always maintain nearer to 1 otherwise excess amount of current is required for a given amount of power. Hence it is calculated by real power unit divided by sum of the square root of real and reactive power units (apparent power).

9 RESULT

9.1 MODEL WITHOUT PLANT SYSTEM

9.1.1 Winter simulation

The initial simulation of the model i.e. a model without plant system, executed for one month from 1st January (2013) to 31st January (2013) during winter climate. In earlier to the analysis of each zone in the model, review of certain parameters of the climate like ambient DB, direct normal solar intensity and wind speed at its geographical location is necessary. Maximum and minimum value occurrence of the above parameters are shown in the tabule:3.

S.NO	PARAMETERS	MAXIMUM VALUE	MINIMUM VALUE
1	Ambient DB	12.7C	-6.4C
2	DN solar intensity	554 W/m^2	0
3	Wind speed	8.5 m/s	0.4

Table 3: **Climate parameters**

The ambient DB graph shown in figure: 49 clearly shows that at each day of a month there is raise and fall of ambient DB. Only at certain days the fall of DB is high and the remaining days shows a gradual increase. This fall and raise definitely affects the indoor environment of the building.

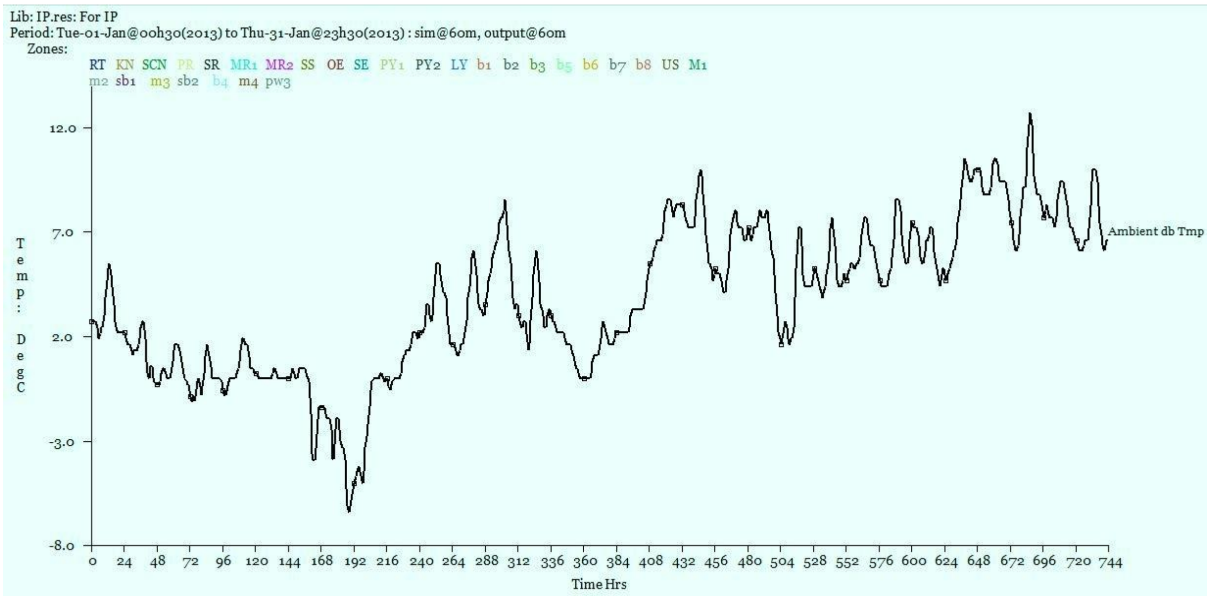


Figure 49: **Graphical representation of ambient DB**

The direct normal solar intensity graph represented in figure: 50 clearly shows that on the first three days the raise of the direct normal solar intensity is at peak, then on the next day there is rapid decrease and reach to zero. After this it shows a gradual raise and sudden fall to zero.

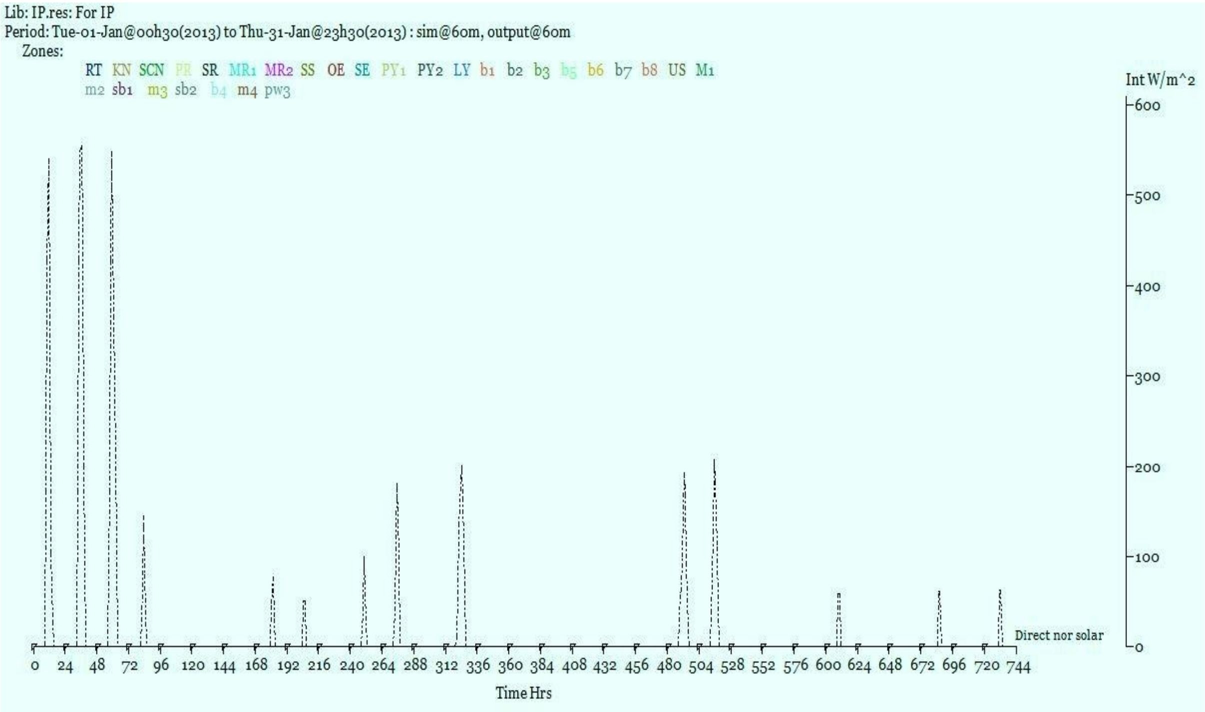


Figure 50: **Graphical representation of DN solar intensity**

Findings of maximum and minimum occurrence of DB temperature and RH of the ground floor zones are shown in table: 4

S.NO	**ZONES**	**DB TEMPERATURE**		**RELATIVE HUMIDITY**	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	RT	20.272	6.6057	100	42.215
2	KN	24.714	13.275	100	29.492
3	SCR	14.571	10.312	67.800	19.934
4	PR	25.491	21.952	33.412	9.8557
5	SR	19.251	11.710	83.919	23.596
6	MR1	21.579	5.1867	100	35.580
7	MR2	20.071	7.160	100	31.562
8	SS	19.705	6.6532	81.977	19.537
9	OE	20.971	7.7073	100	30.337
10	SE	13.270	9.3343	81.977	19.537
11	PY1	16.587	13.573	100	30.337

12	PY2	15.088	11.341	77.014	21.516
13	LY	16.460	8.8345	57.934	16.727

Table 4: **DB temperature and relative humidity for ground floor zones**

Graphical representation of the dry bulb temperature of the zones below are tend to connect with the plant system

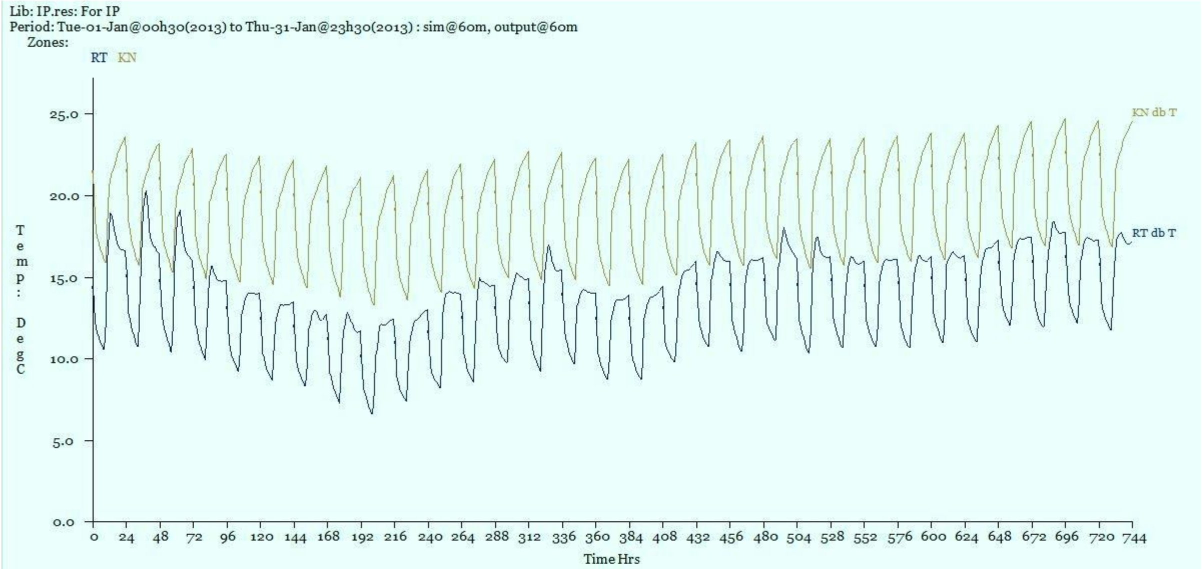


Figure 51: **DB temperature of KN and RT**

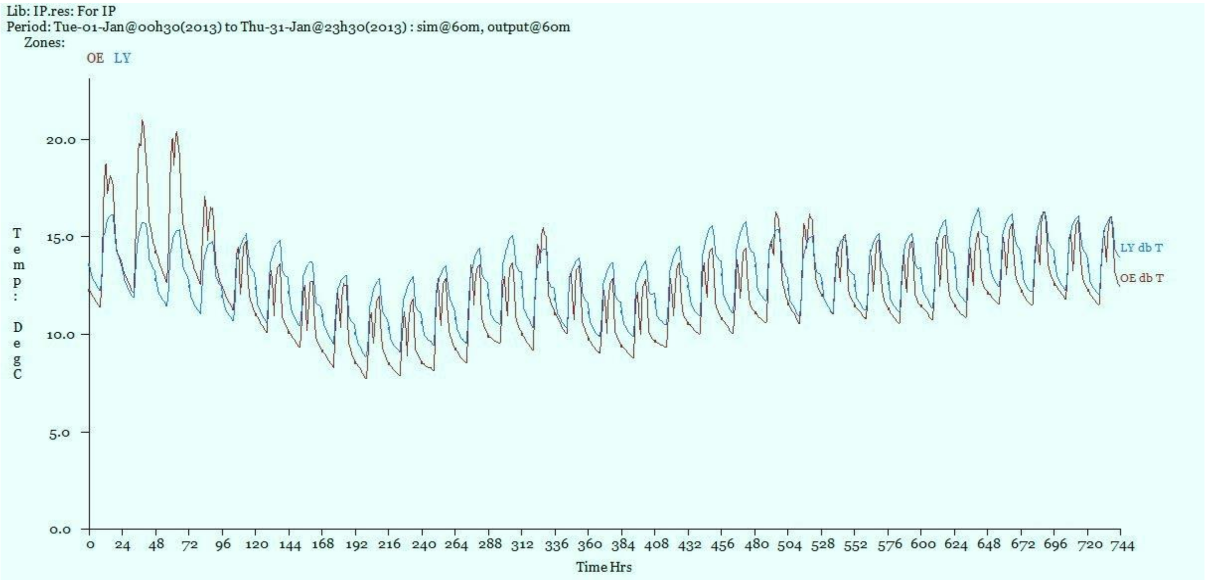


Figure 52: **DB temperature of LY and OE**

Graphical representation of the relative humidity (RH) of the zones below are tend to connect with the plant system

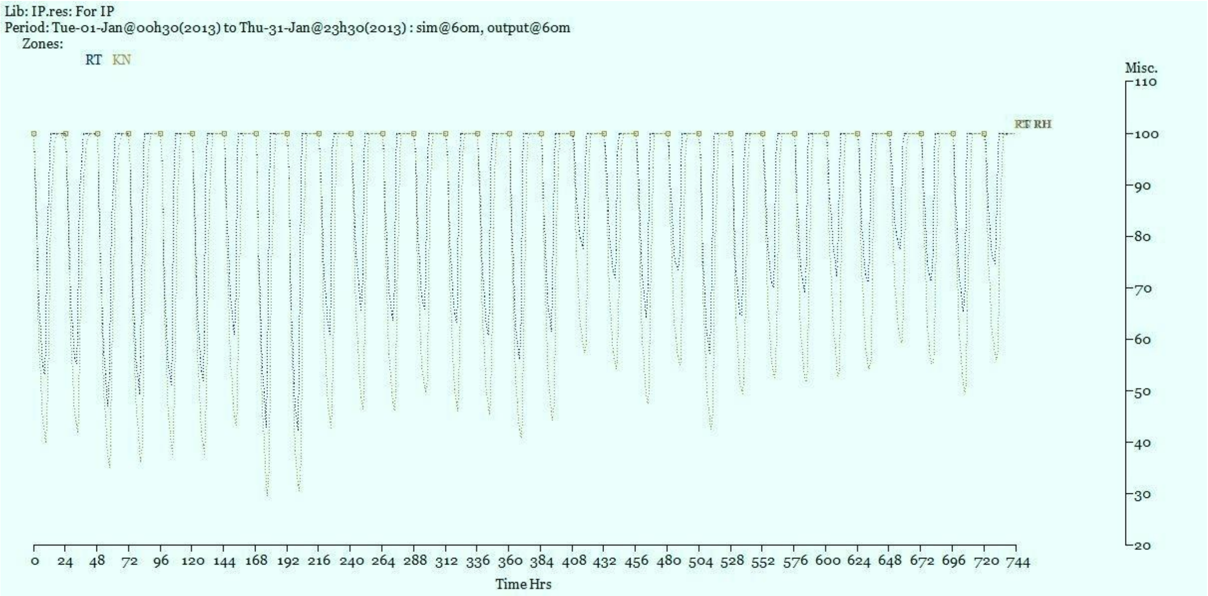


Figure 53: **RH of KN and RT**

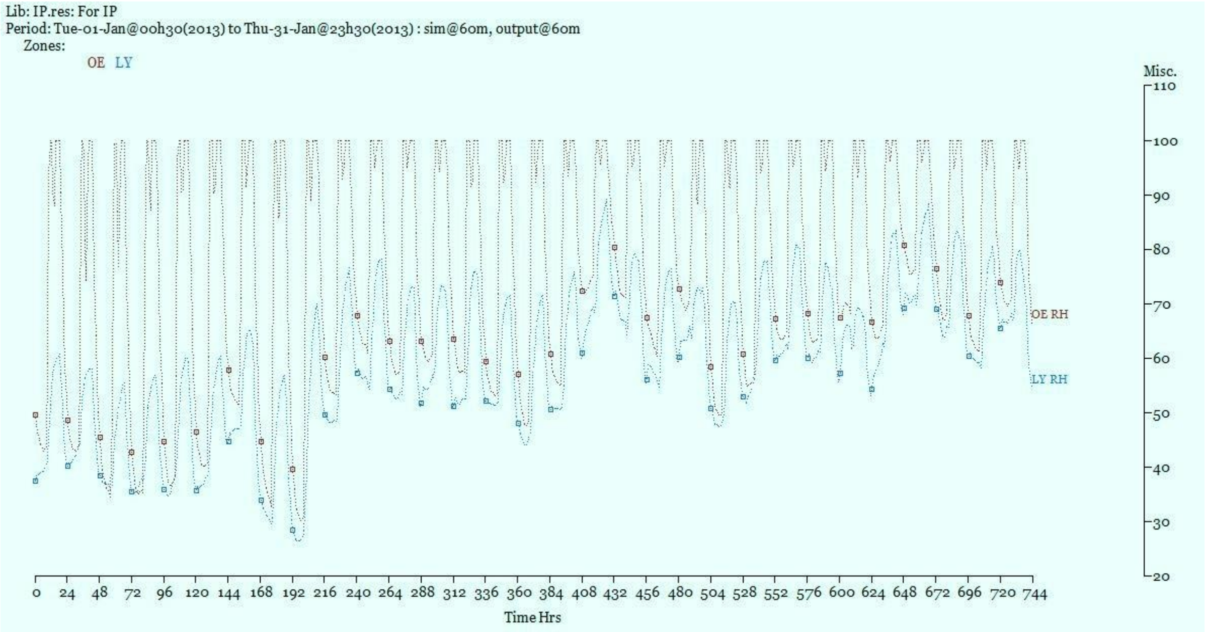


Figure 54: **RH of OE and LY**

Findings of maximum and minimum occurrence of DB temperature and RH for the first floor zones are shown in table 5.

S.NO	**ZONES**	**DB TEMPERATURE**		**RELATIVE HUMIDITY**	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	B1	12.563	4.754	100	35.106

2	B2	11.708	5.535	100	33.276
3	B3	11.640	5.252	100	33.921
4	B4	10.392	3.2131	100	36.910
5	B5	12.574	6.9819	100	30.616
6	B6	14.356	9.4469	100	25.202
7	B7	14.486	9.8260	100	24.289
8	B8	15.144	7.2976	100	28.665
9	M1	13.942	7.756	100	27.291
10	M2	13.801	7.4377	100	27.779
11	M3	12.467	6.3312	100	30.307
12	M4	11.422	5.657	100	31.030
13	SB1	12.548	5.580	100	31.438
14	SB2	10.695	4.44	100	34.558
15	PW3	13.739	10.593	71.238	20.391
16	US	19.120	9.0241	74.102	19.775

Table 5: **DB temperature and relative humidity of top floor zones**

Graphical representation of the dry bulb temperature of the zones below are tend to connect with the plant system

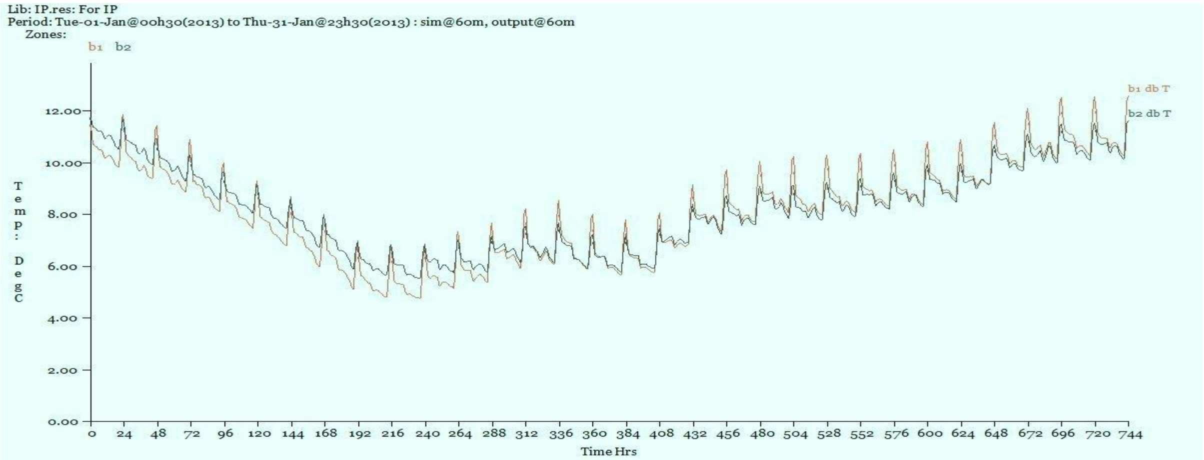


Figure 55: DB temperature of B1 and B2

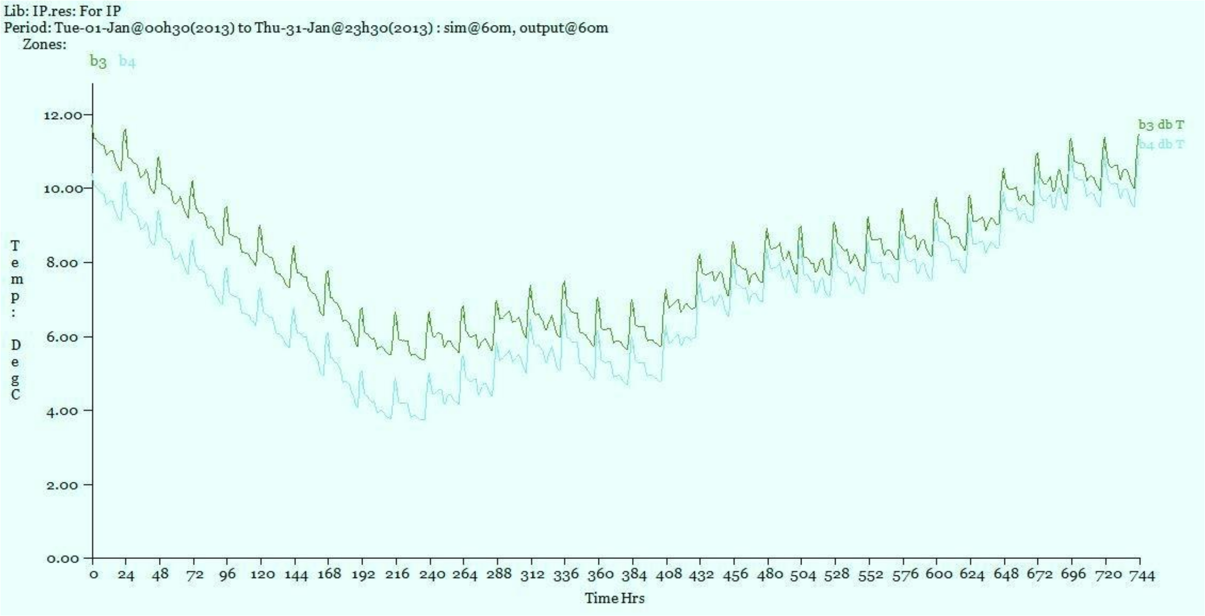


Figure 56: DB temperature of B3 and B4

Graphical representation of the relative humidity (RH) of the zones below are tend to connect with the plant system

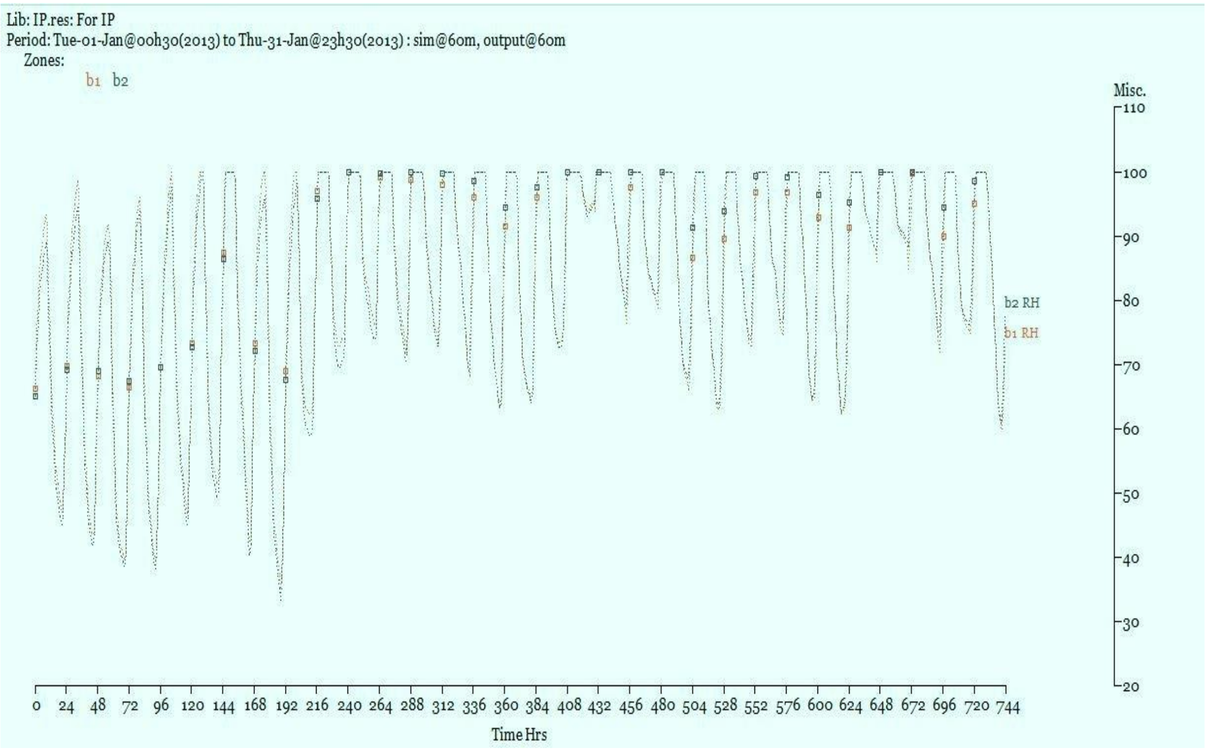


Figure 57: RH of B1 and B2

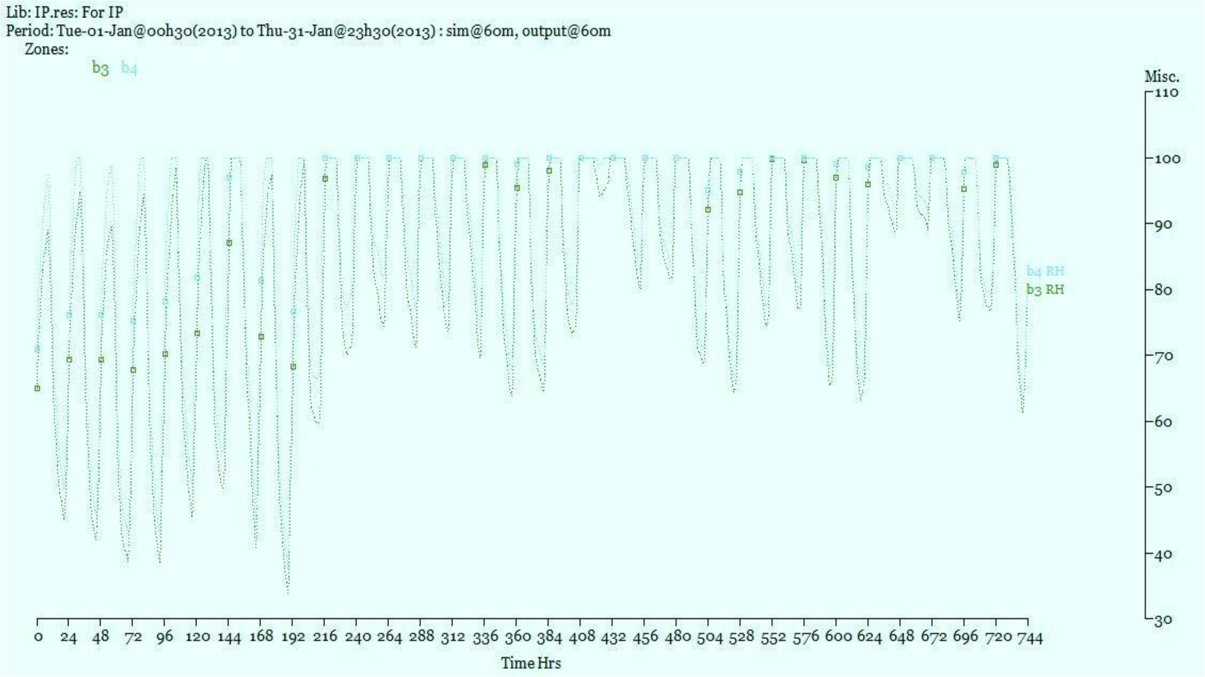


Figure 58: RH of B3 and B4

The above dry bulb temperature graphs of both ground and first floors zones clearly shows the periodic raise and fall of temperature. This temperature raise could be influenced by number of factors like: number of occupants, small equipment's, lighting and outdoor temperature.

Further the relative humidity graphs of both ground and first floor zones clearly shows the occurrence point at each day of the zones. As discussed in the chapter 5.2 most people will feel comfort with the RH in the range of 40% to 60% and human comfort condition also depends on relative humidity exist in a place. In most of the days of the above graphs, relative humidity level is above 60%. In this case the occupant will definitely feel to be discomfort.

9.1.2 ***<u>Summer simulation</u>***

The simulation of the model without plant system, executed for one month during summer season from 1st June (2013) to 30th June (2013). Examination of certain parameters of the climate like ambient DB, direct normal solar intensity and wind speed at its geographical location is necessary to see its impact on the indoor environment of the building. Maximum and minimum value occurrence of the above parameters are in table: 6

S.NO	PARAMETERS	MAXIMUM VALUE	MINIMUM VALUE

1	Ambient DB	20.8C	5C
2	DN solar intensity	766.5 W/m^2	0
3	Wind speed	7.4 m/s	0

Table 6: **Climate parameters**

The ambient DB graph shown in figure: 59 clearly shows the temperature characteristics at summer season. This temperature is comparatively greater than the winter. As well as this visualizes the effect in indoor temperature, relative humidity and comfort.

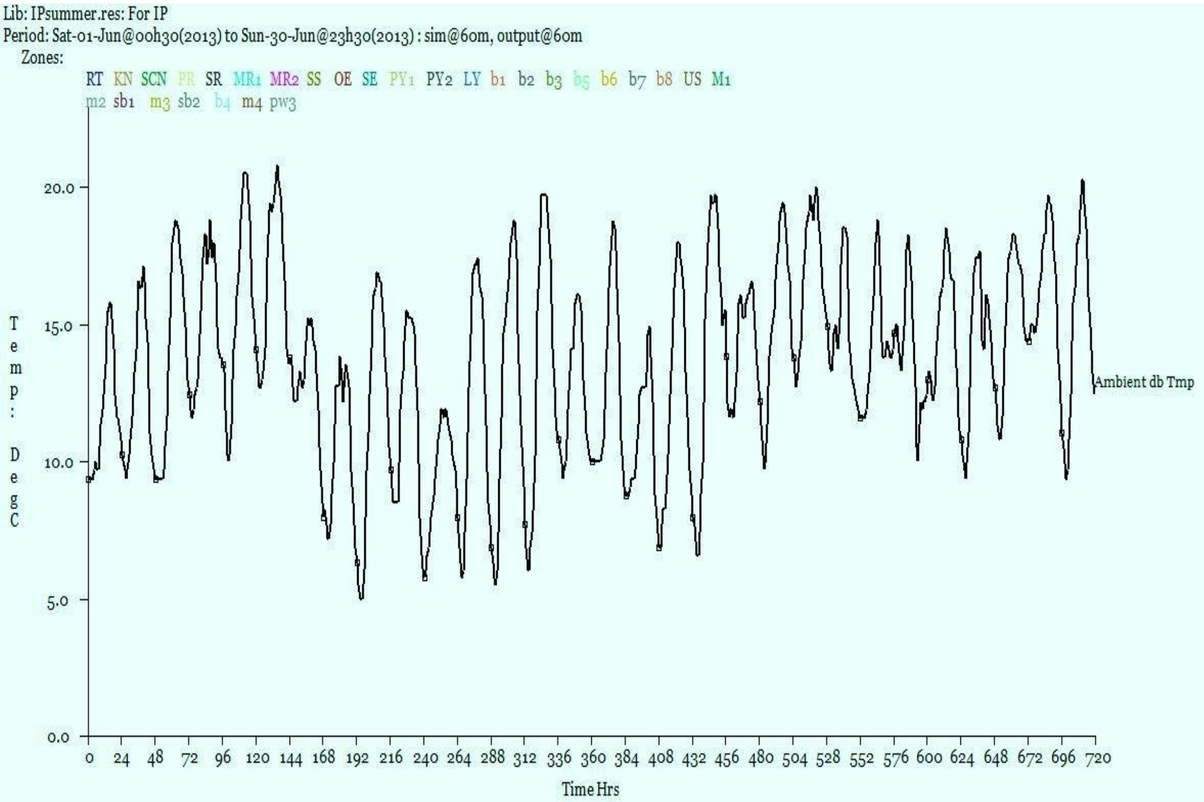


Figure 59: **Graphical representation of ambient DB temperature**

The direct normal solar intensity graph represented shown in figure: 60 clearly shows the intensity of solar radiation during summer season.

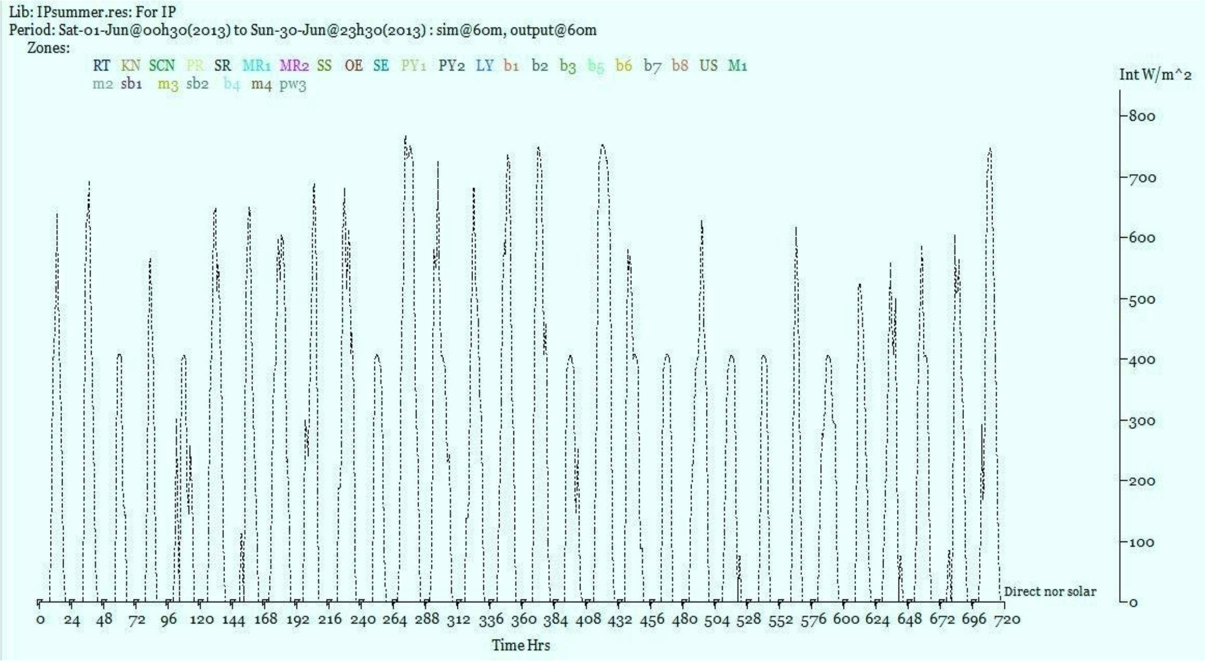


Figure 60: **Graphical representation of DN solar intensity**

Findings of maximum and minimum occurrence of DB temperature and RH of the ground floor zones are shown in table: 7

S.NO	ZONES	DB TEMPERATURE		RELATIVE HUMIDITY	
		MAXIMUM Temp. (C)	MINIMUM Temp. (C)	MAXIMUM (%)	MINIMUM (%)
1	RT	33.403	18.924	100	34.10
2	KN	31.316	19.567	97.944	35.32
3	SCR	21.181	15.921	69.797	30.05
4	PR	31.961	27.208	36.750	14.925
5	SR	26.419	19.292	72.272	29.337
6	MR1	32.064	17.885	89.499	31.937
7	MR2	30.051	18.218	100	31.945
8	SS	30.77	19.330	52.881	20.023
9	OE	32	19.535	100	29.773
10	SE	21.07	16.830	69.590	27.621
11	PY1	23.413	18.996	60.833	24.709
12	PY2	22.508	18.363	63.309	26.713
13	LY	24.898	16.287	73.693	31.857

Table 7: **DB temperature and relative humidity of ground floor zones**

Graphical representation of the dry bulb temperature of the zones below are tend to connect with the plant system

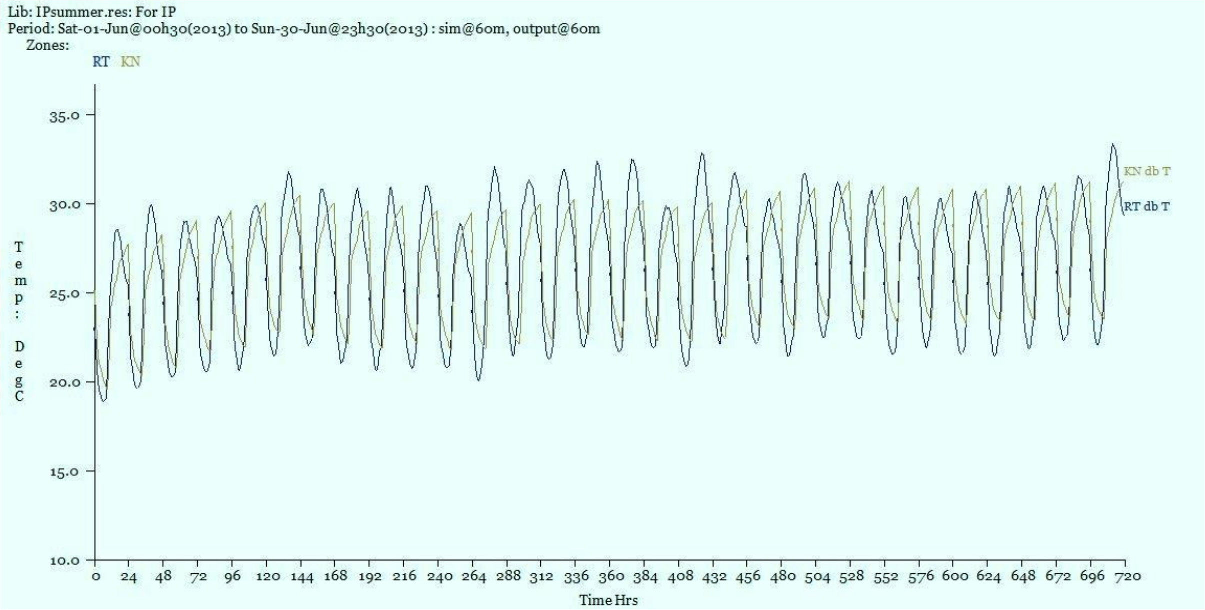


Figure 61: **DB temperature of KN and RT**

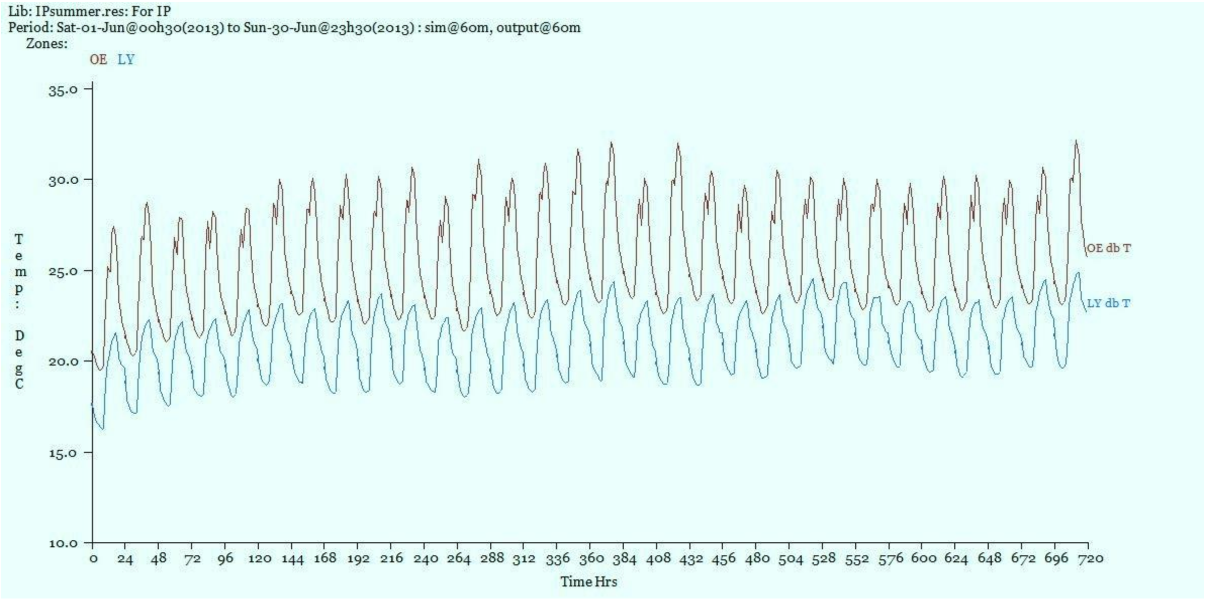


Figure 62: **DB temperature of LY and OE**

Graphical representation of the relative humidity (RH) of the zones below are tend to connect with the plant system

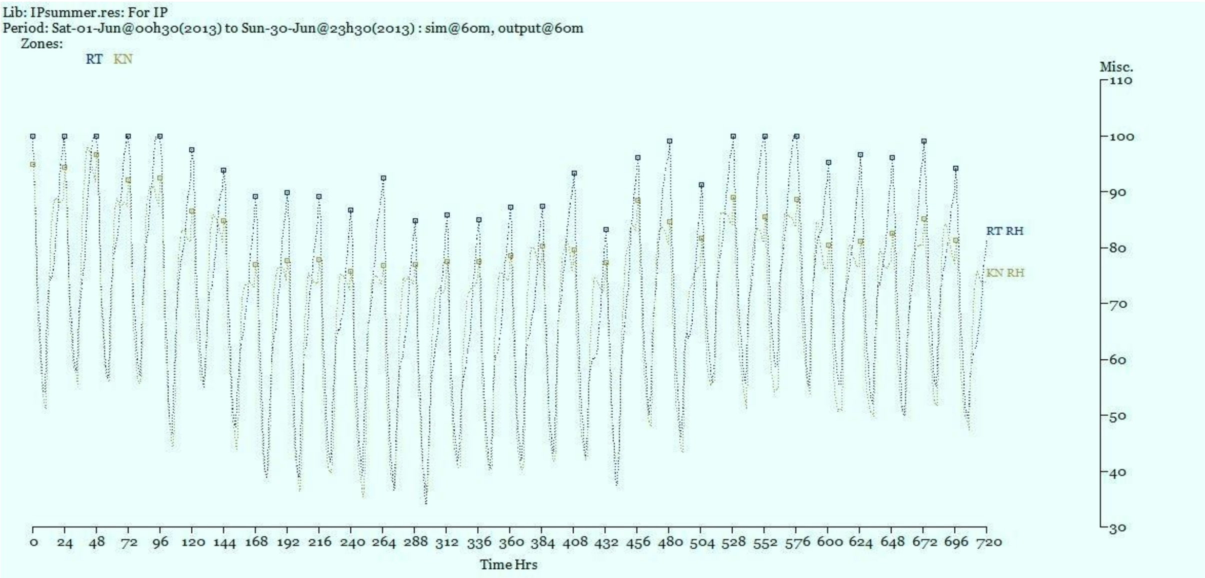


Figure 63: **RH of KN and RT**

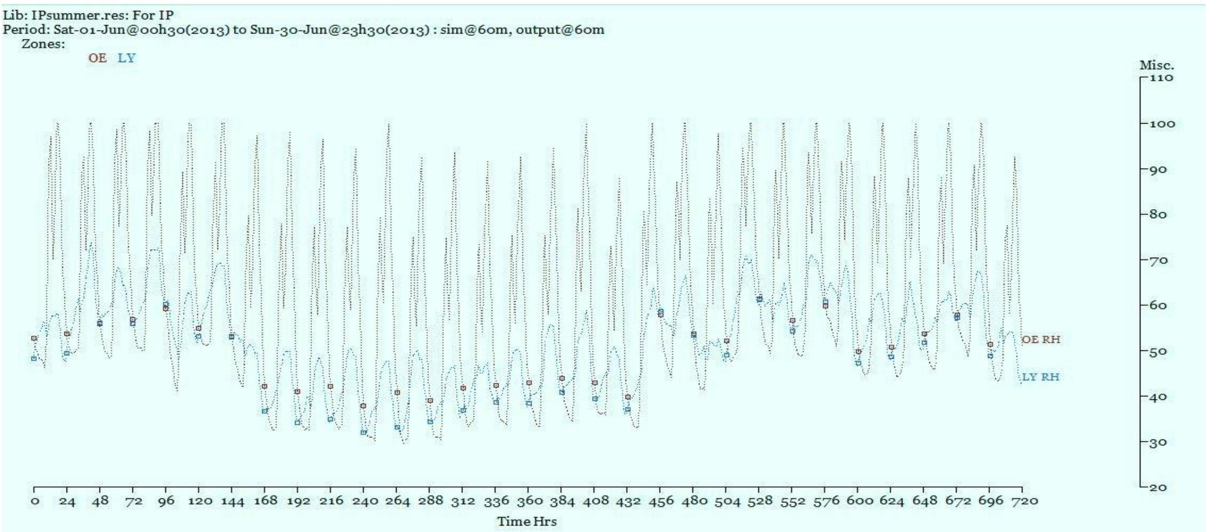


Figure 64: **RH of OE and LY**

Findings of maximum and minimum occurrence of DB temperature and RH of the first floor zones are shown in table:8

S.NO	**ZONES**	**DB TEMPERATURE**		**RELATIVE HUMIDITY**	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	B1	28.645	18.998	74.966	22.080
2	B2	28.175	18.646	77.245	22.013

3	B3	27.786	18.539	77.981	22.625
4	B4	26.403	18.066	67.549	25.235
5	B5	23.169	16.647	89.396	32.708
6	B6	22.807	16.268	91.204	33.304
7	B7	24.172	16.773	87.966	30.346
8	B8	27.794	18.882	71.706	23.926
9	M1	26.758	18.061	68.059	24.839
10	M2	26.833	18.107	67.836	27.754
11	M3	22.321	15.793	77.218	33.548
12	M4	18.447	13.142	93.397	41.463
13	SB1	26.268	17.847	68.892	26.338
14	SB2	21.555	15.880	76.944	34.539
15	PW3	22.264	1.478	66.649	27.4
16	US	32.024	20.635	45.476	18.664

Table 8: **DB temperature and relative humidity of top floor zones**

Graphical representation of the dry bulb temperature of the zones below are tend to connect with the plant system

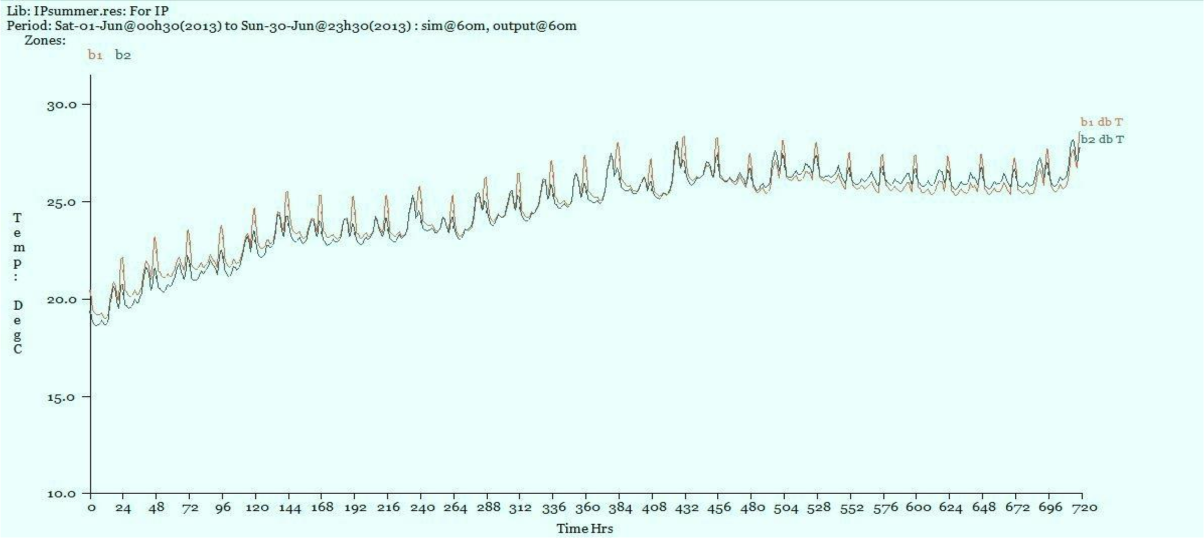


Figure 65: **DB temperature of B1 and B2**

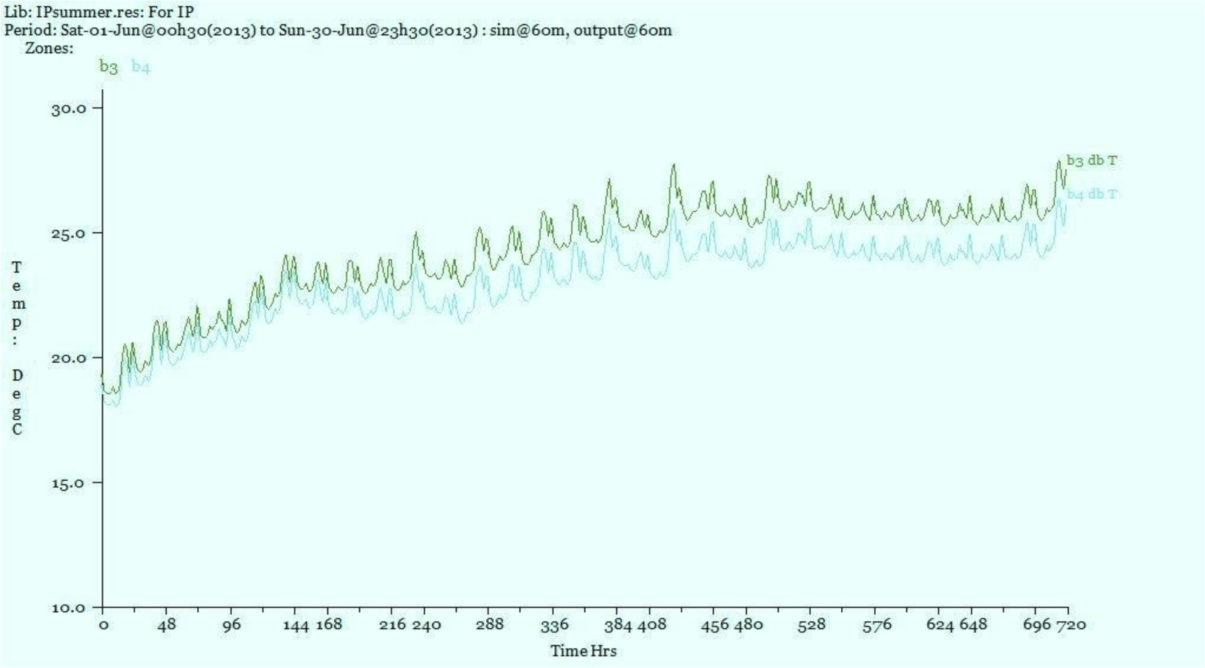


Figure 66: DB temperature of B3 and B4

Graphical representation of the relative humidity (RH) of the zones below are tend to connect with the plant system

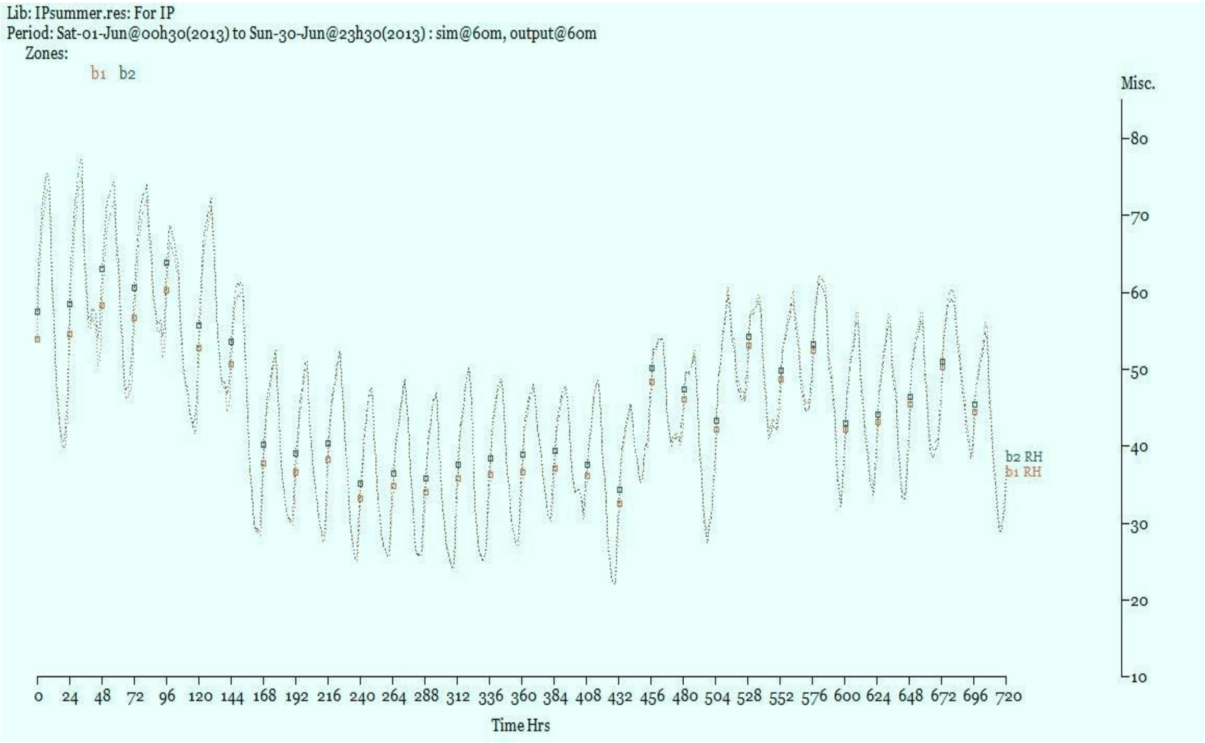


Figure 67: RH of B1 and B2

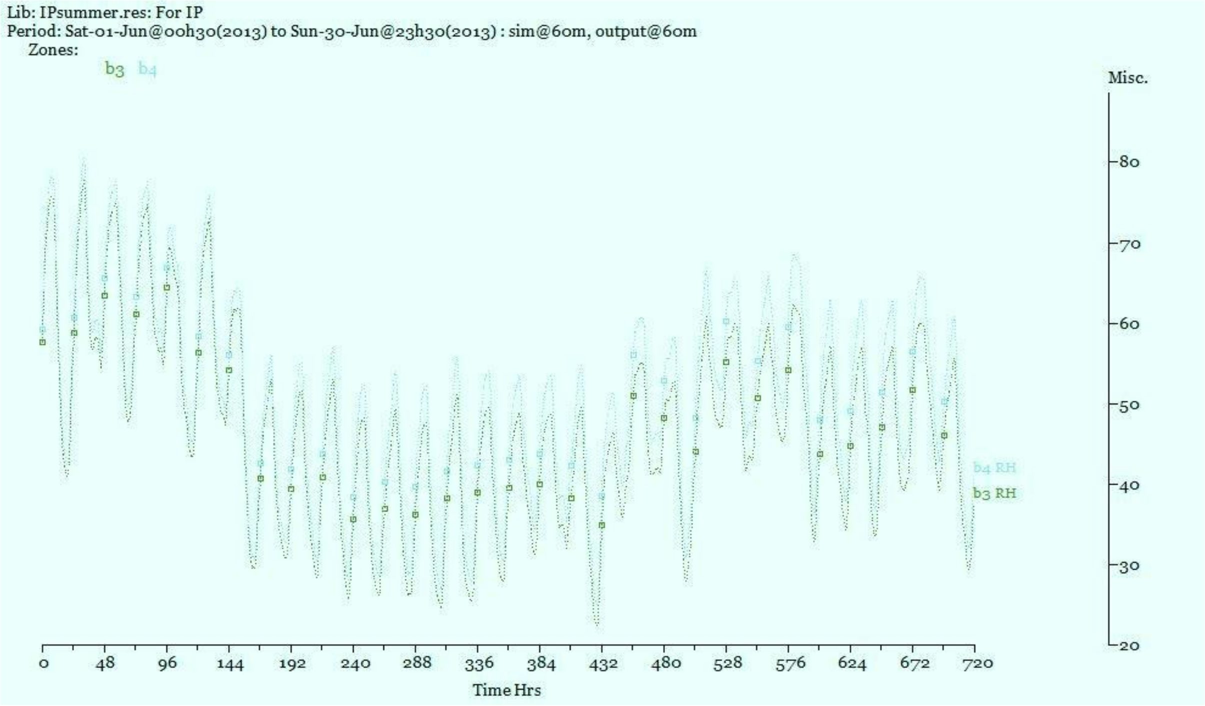


Figure 68: **RH of B3 and B4**

The periodic raise and fall of dry bulb temperature of the zones are due to the above said factors in winter simulation. Further from the relative humidity graphs of both ground and first floor zones we can see that maximum and minimum point reached is less than the winter.

9.2 MODEL WITH PLANT SYSTEM

9.2.1 Winter simulation

The simulation of model connected to MVHR system with heating coil in it, executed during winter climate from 1st January (2013) to 31st January (2013).

Zone DB and relative humidity of ground floor zones connected with the plant system attained from the simulation are shown in table: 9

S.NO	**ZONES**	**DB TEMPERATURE**		**RELATIVE HUMIDITY**	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	RT	24.6	11.66	58.265	20.014
2	KN	27.5	16.427	35.482	13.237
3	OE	30.414	16.866	28.483	12.444
4	LY	25.247	14.452	39.434	14.018

Table 9: **DB temperature and relative humidity of ground floor zones**

Graphical representation of the dry bulb temperature of the zones below are connected with the plant system

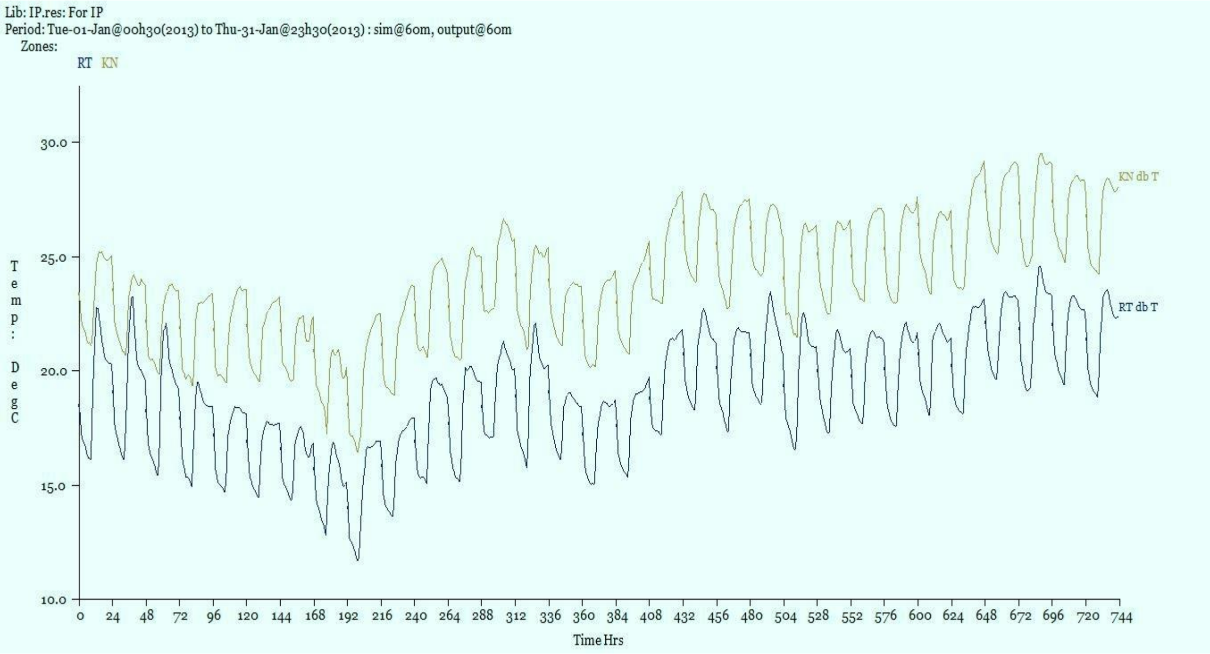


Figure 69: DB temperature of KN and RT

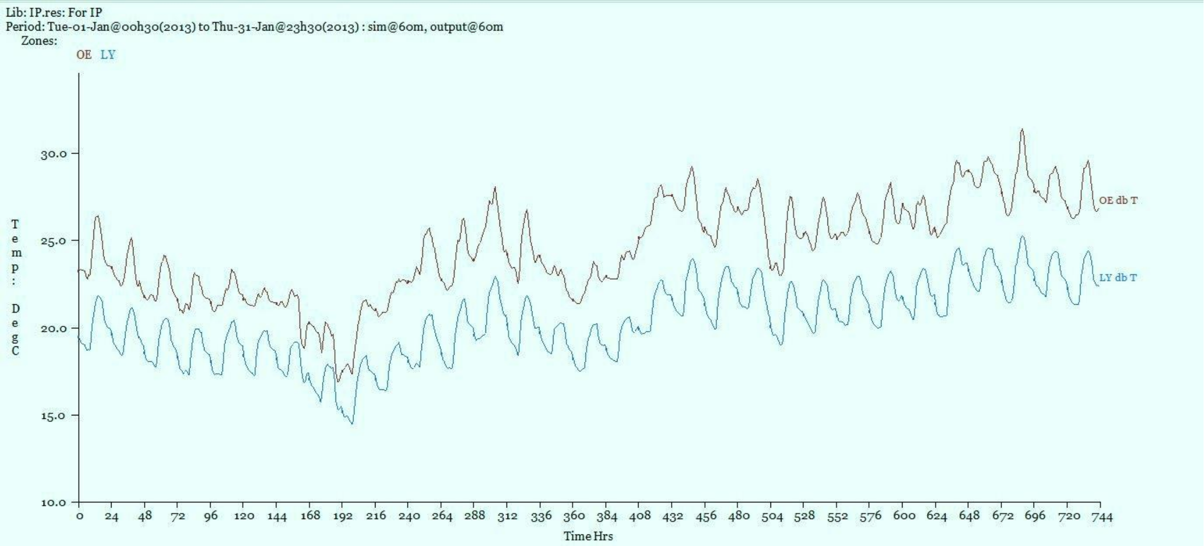


Figure 70: DB temperature of LY and OE

Graphical representation of the relative humidity (RH) of the zones below are connected with the plant system

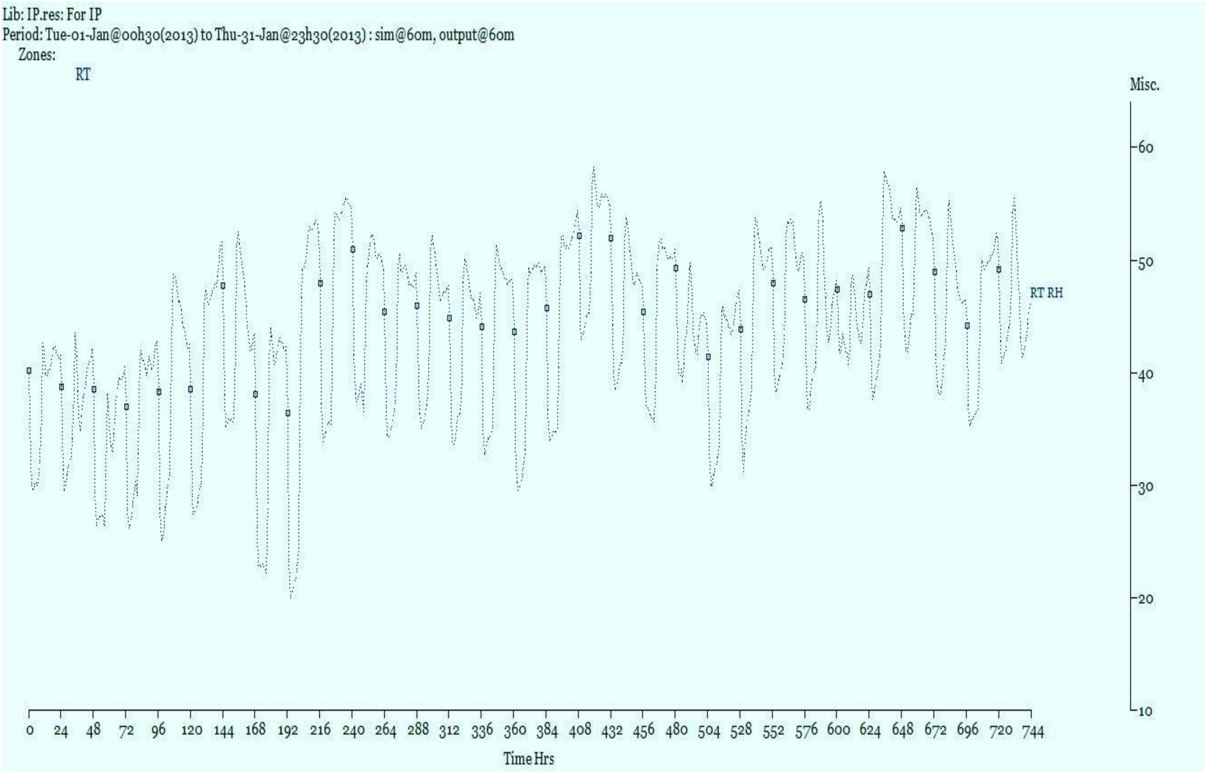


Figure 71: **RH of RT**

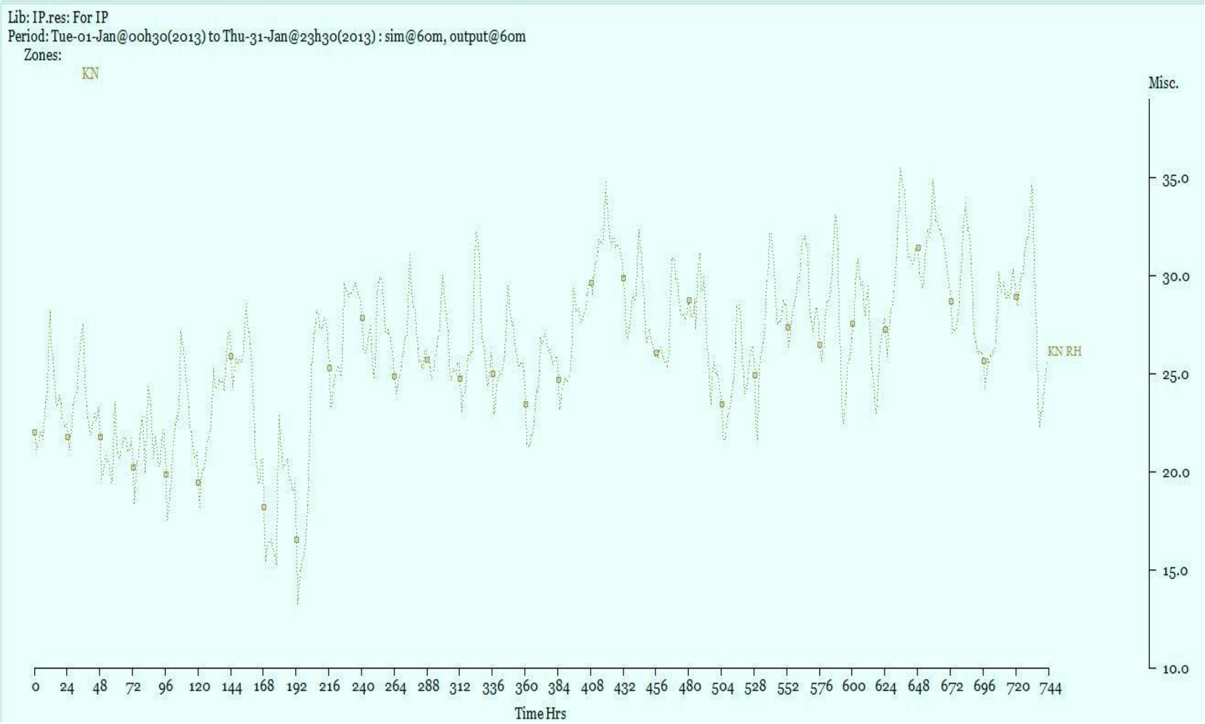


Figure 72: **RH of KN**

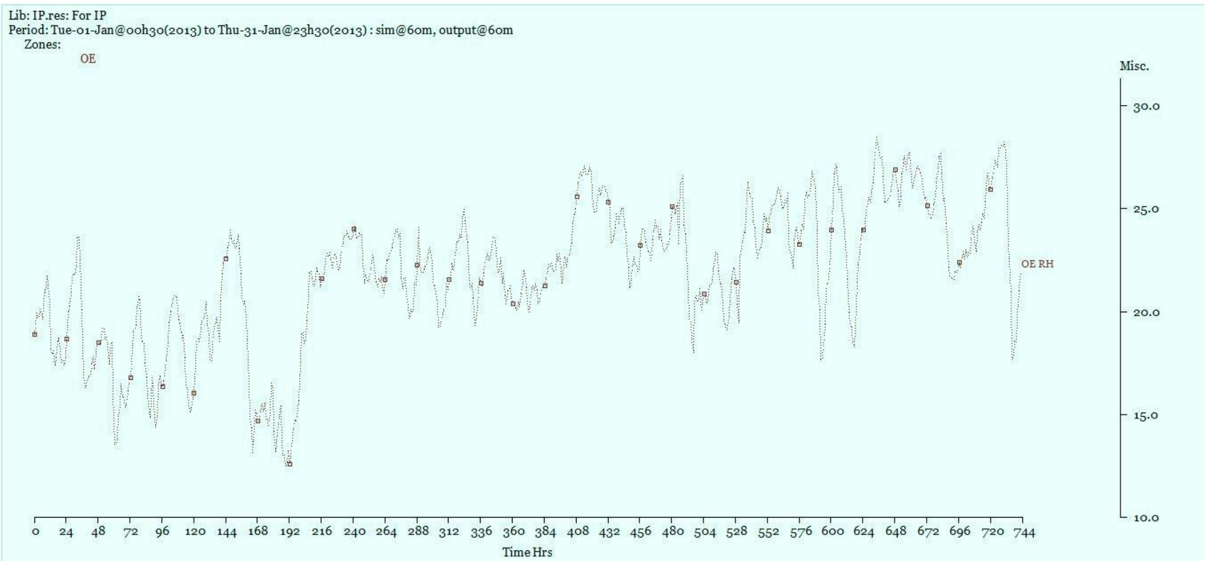


Figure 73: **RH of OE**

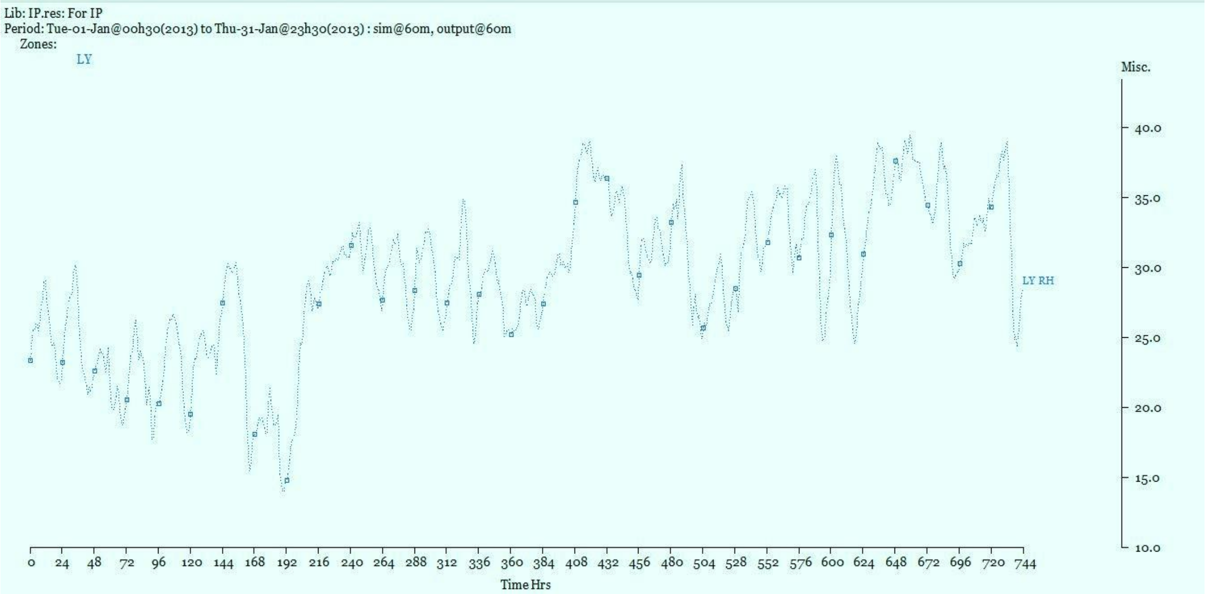


Figure 74: **RH of LY**

Zone DB and relative humidity of first floor zones connected with the plant system attained from the simulation are shown in table: 10

S.NO	**ZONES**	**DB TEMPERATURE**		**RELATIVE HUMIDITY**	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	B1	27.548	13.934	33.772	15.408
2	B2	27.847	14.187	33.200	15.301
3	B3	27.844	14.183	33.207	15.303

4	B4	27.508	13.869	33.889	15.611

Table 10: **DB temperature and relative humidity of ground floor zones**

Graphical representation of the dry bulb temperature of the zones below are connected with the plant system

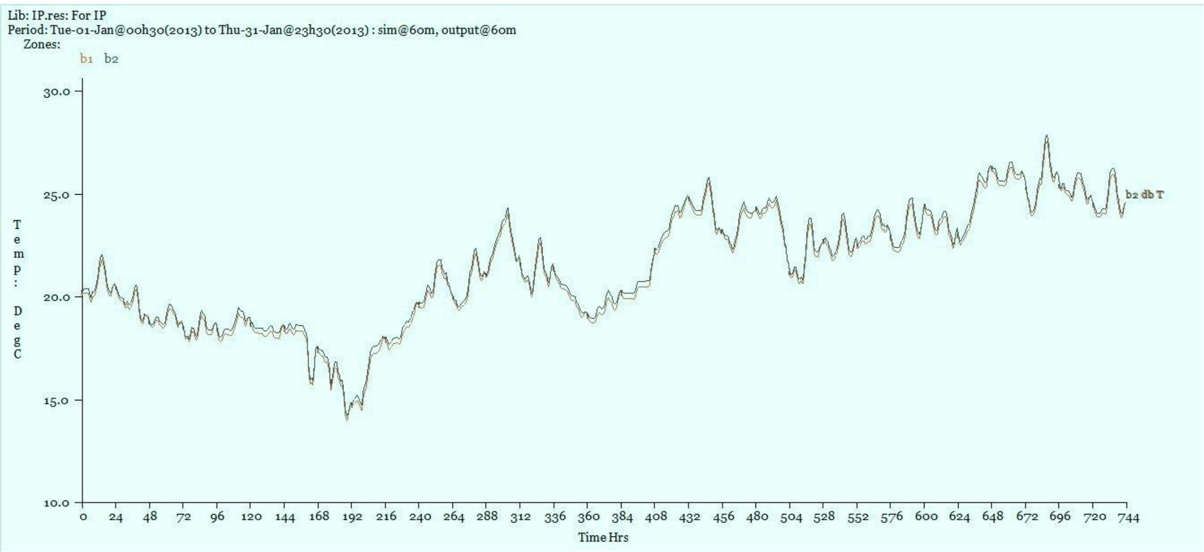


Figure 75: **DB temperature of B1 and B2**

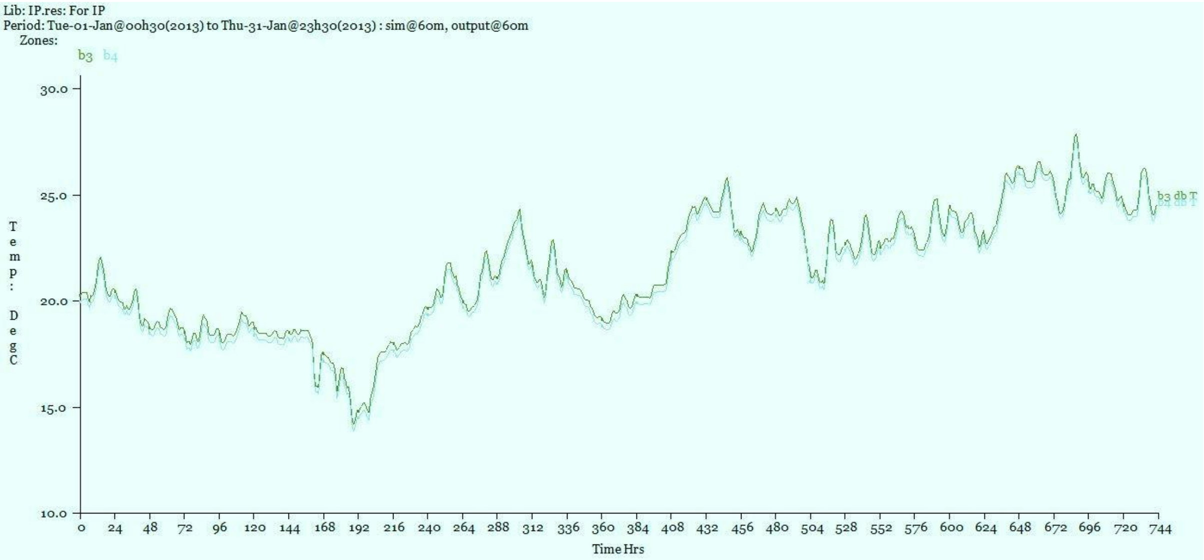


Figure 76: **DB temperature of B3 and B4**

Graphical representation of the relative humidity (RH) of the zones below are connected with the plant system

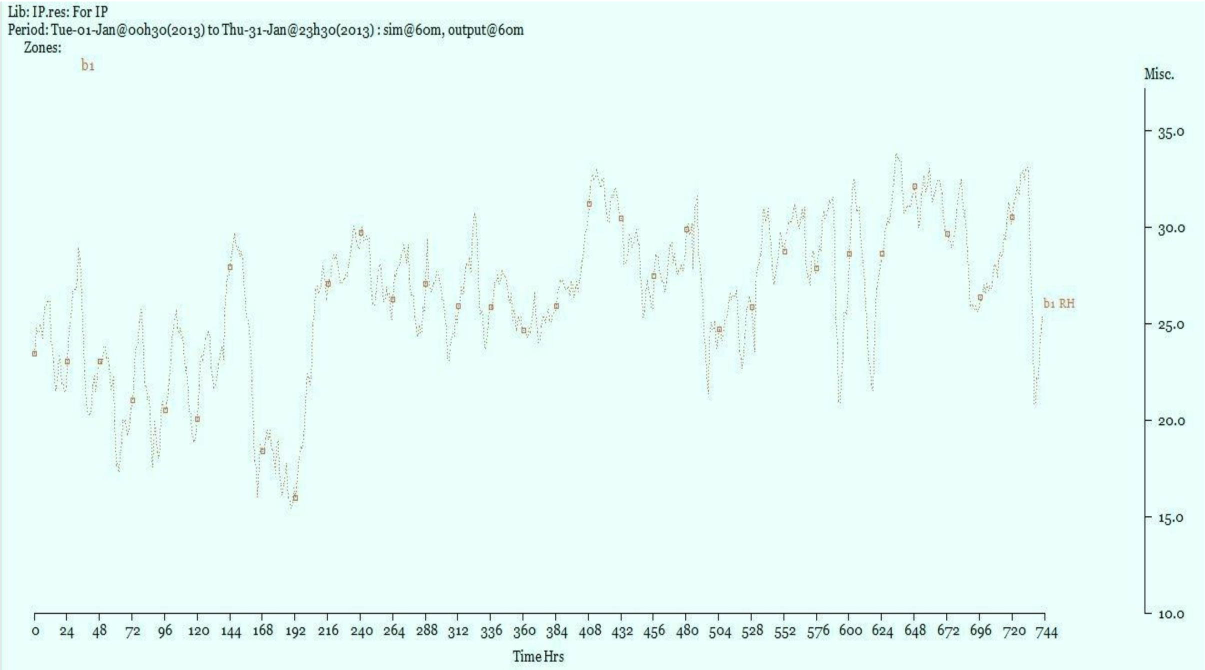


Figure 77: **RH of B1**

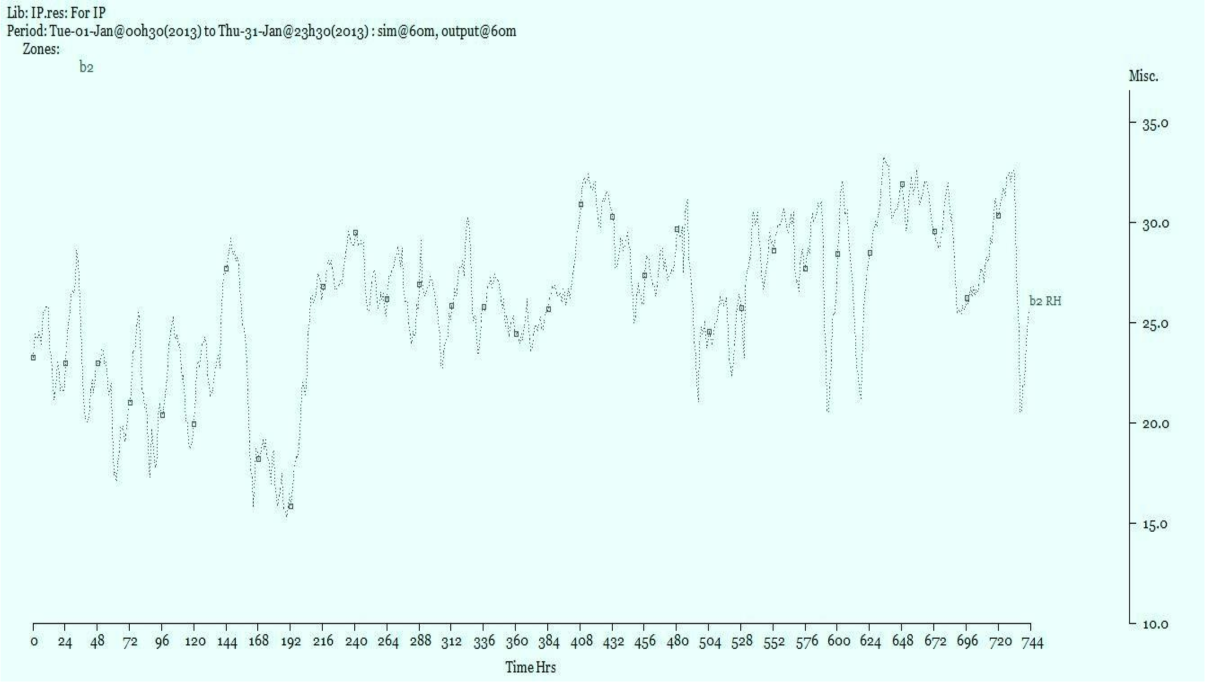


Figure 78: **RH of B2**

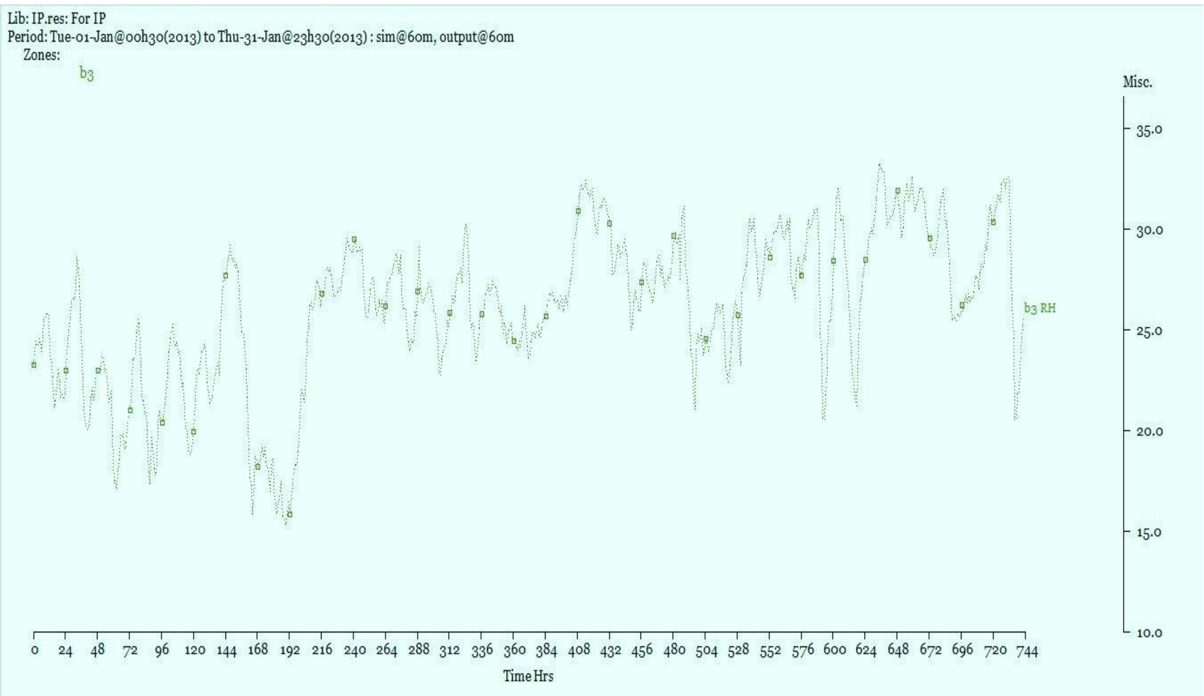


Figure 79: RH of B3

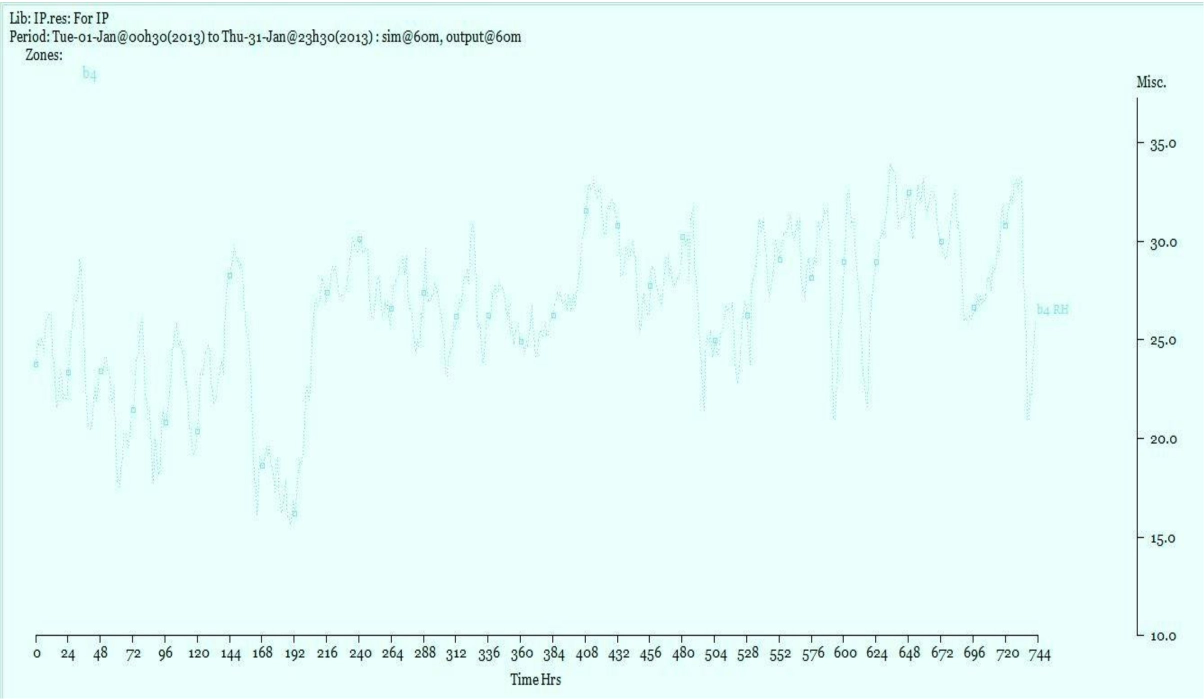


Figure 80: RH of B3

The above graphs and tabular result shows that there is an advancement in zone DB temperature as well as in relative humidity when compared with the previous winter simulation result.

9.2.2 Summer simulation

The simulation of model connected to MVHR system with cooling coil in it, executed during summer climate from 1st June (2013) to 30th June (2013).

Zone DB and relative humidity of ground floor zones connected with the plant system attained from the simulation are shown in table: 11

S.NO	ZONES	DB TEMPERATURE		RELATIVE HUMIDITY	
		MAXIMUM Temp. (C)	**MINIMUM Temp. (C)**	**MAXIMUM (%)**	**MINIMUM (%)**
1	RT	27	15.184	72.845	34.470
2	KN	23.553	13.441	78.090	33.327
3	OE	22.035	10.413	81.703	25.538
4	LY	22.016	13.417	78.796	32.008

Table 11: **DB temperature and relative humidity of ground floor zones**

Graphical representation of the dry bulb temperature of the zones below are connected with the plant system

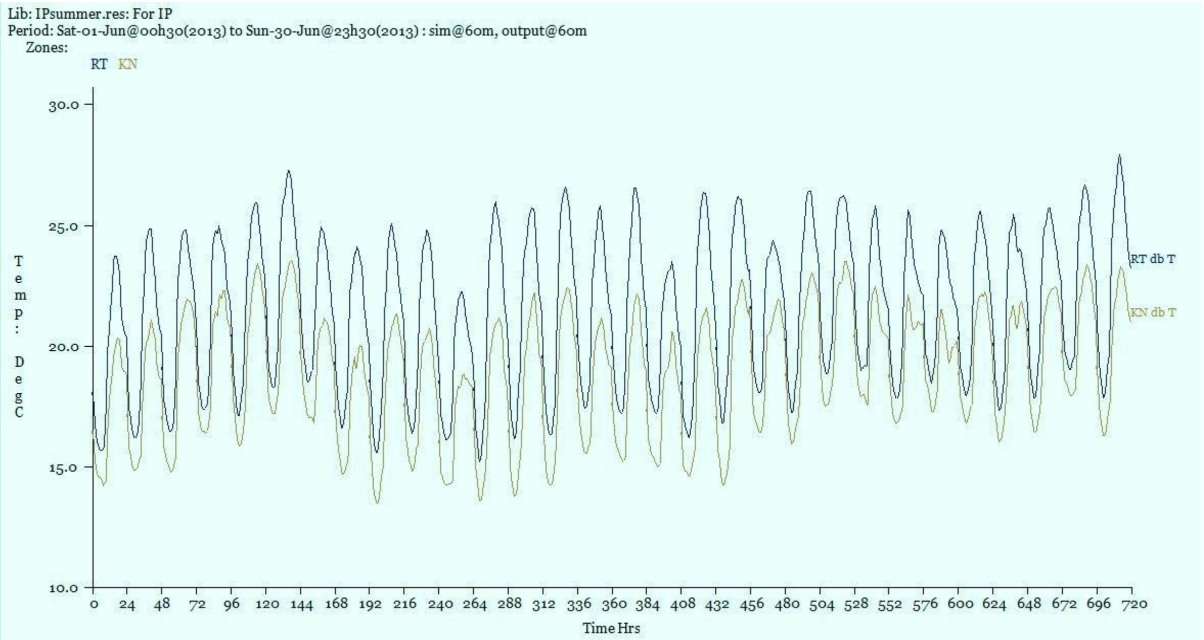


Figure 81: **DB temperature of KN and RT**

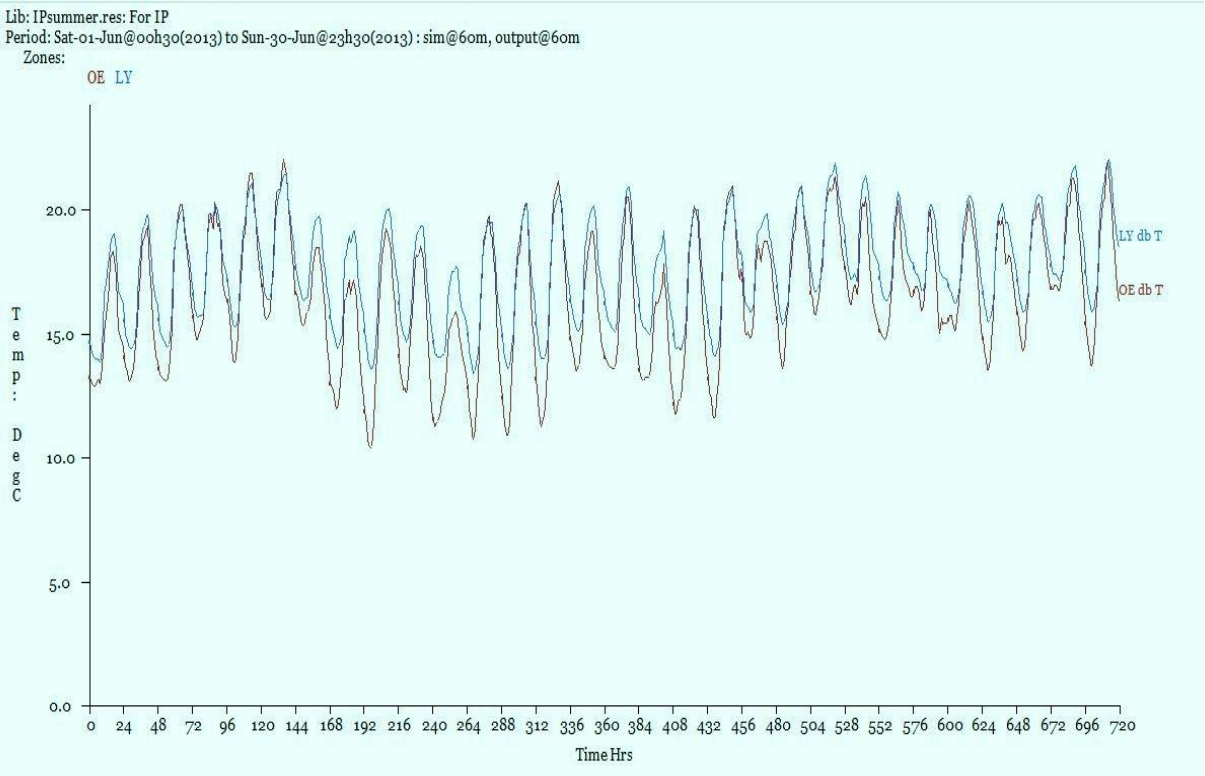


Figure 82: **DB temperature of LY and OE**

Graphical representation of the relative humidity (RH) of the zones below are: the zones tend to connect with the plant system

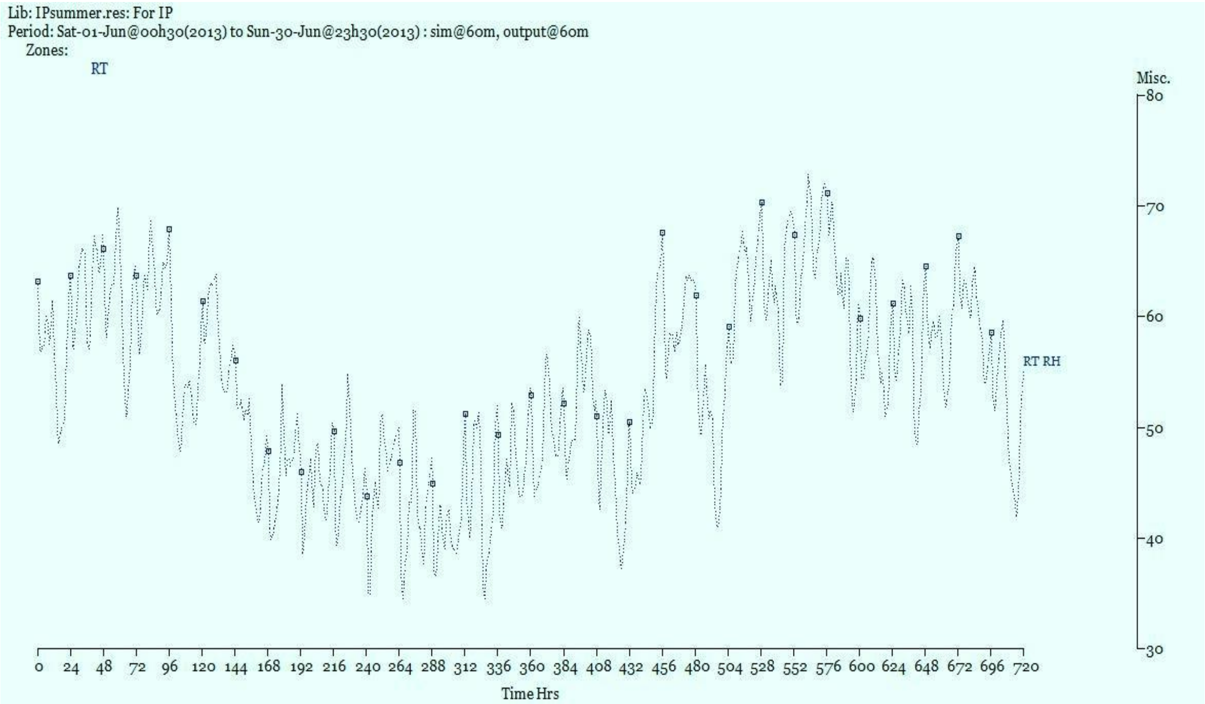


Figure 83: **RH of RT**

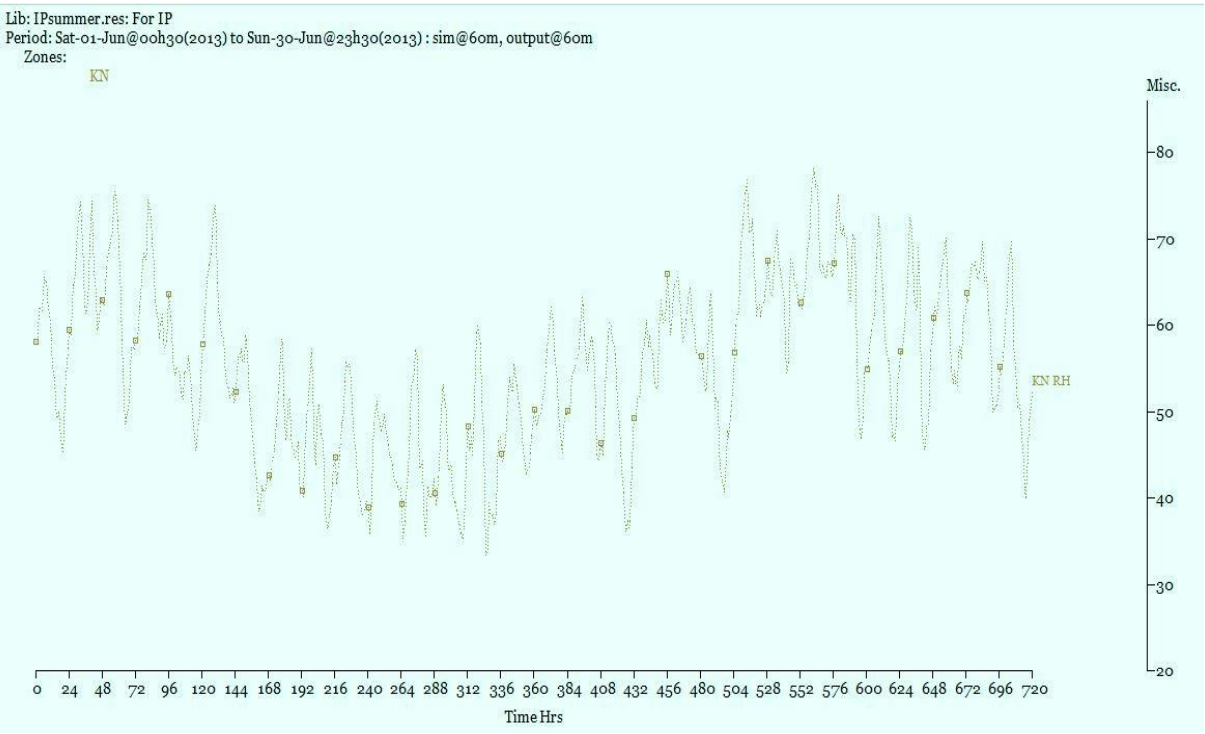


Figure 84: **RH of KN**

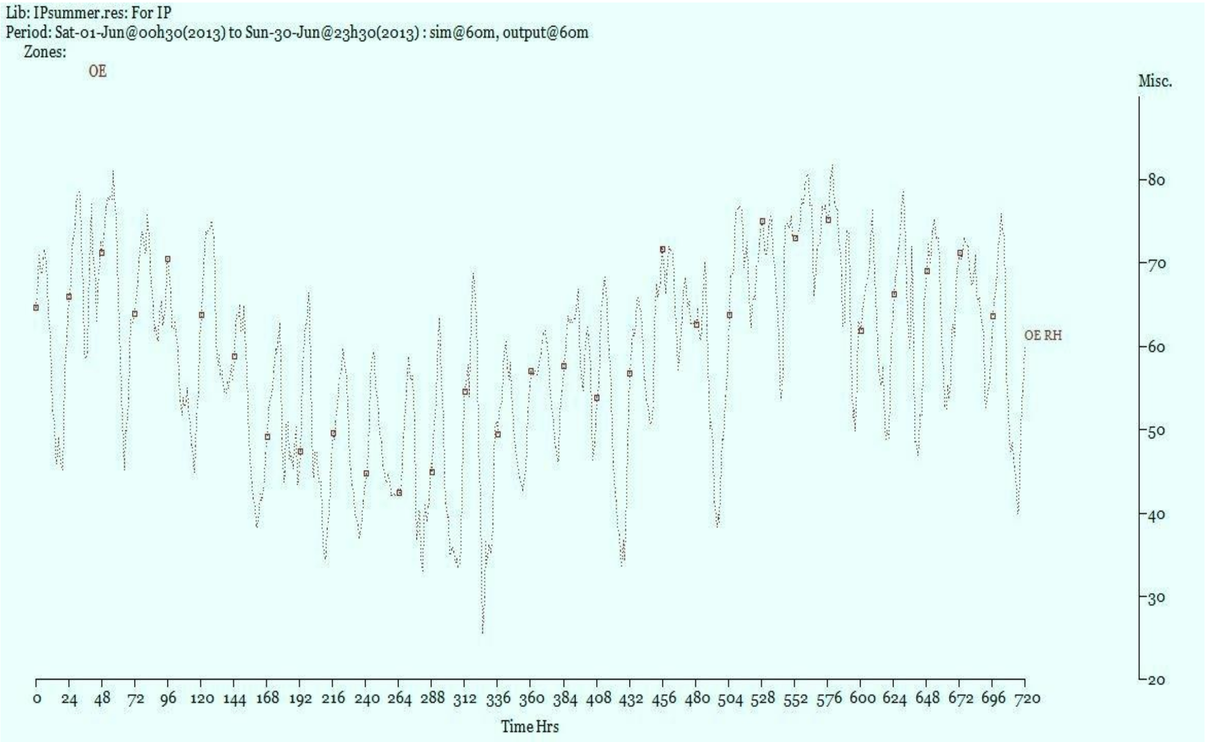


Figure 85: **RH of OE**

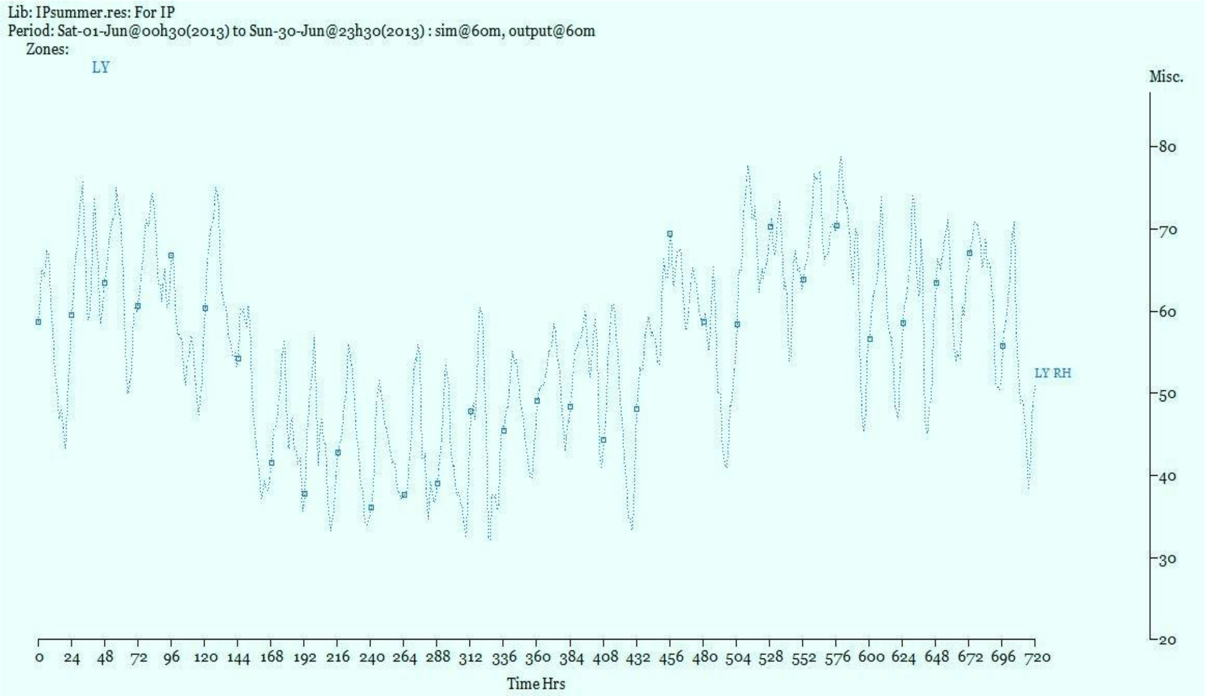


Figure 86: **RH of LY**

This simulation result clearly displays the enhancement stage between the plant system with cooling coil and a model without plant system.

9.3 COMPARISON OF INDOOR ENVIRONMENT COMFORT

The thermal comfort in ESP-r was calculated from Fanger's model, who mathematically expressed a predicted mean index which is shown below

$$PMV = (0.303e^{-0.036M} + 0.028)L$$

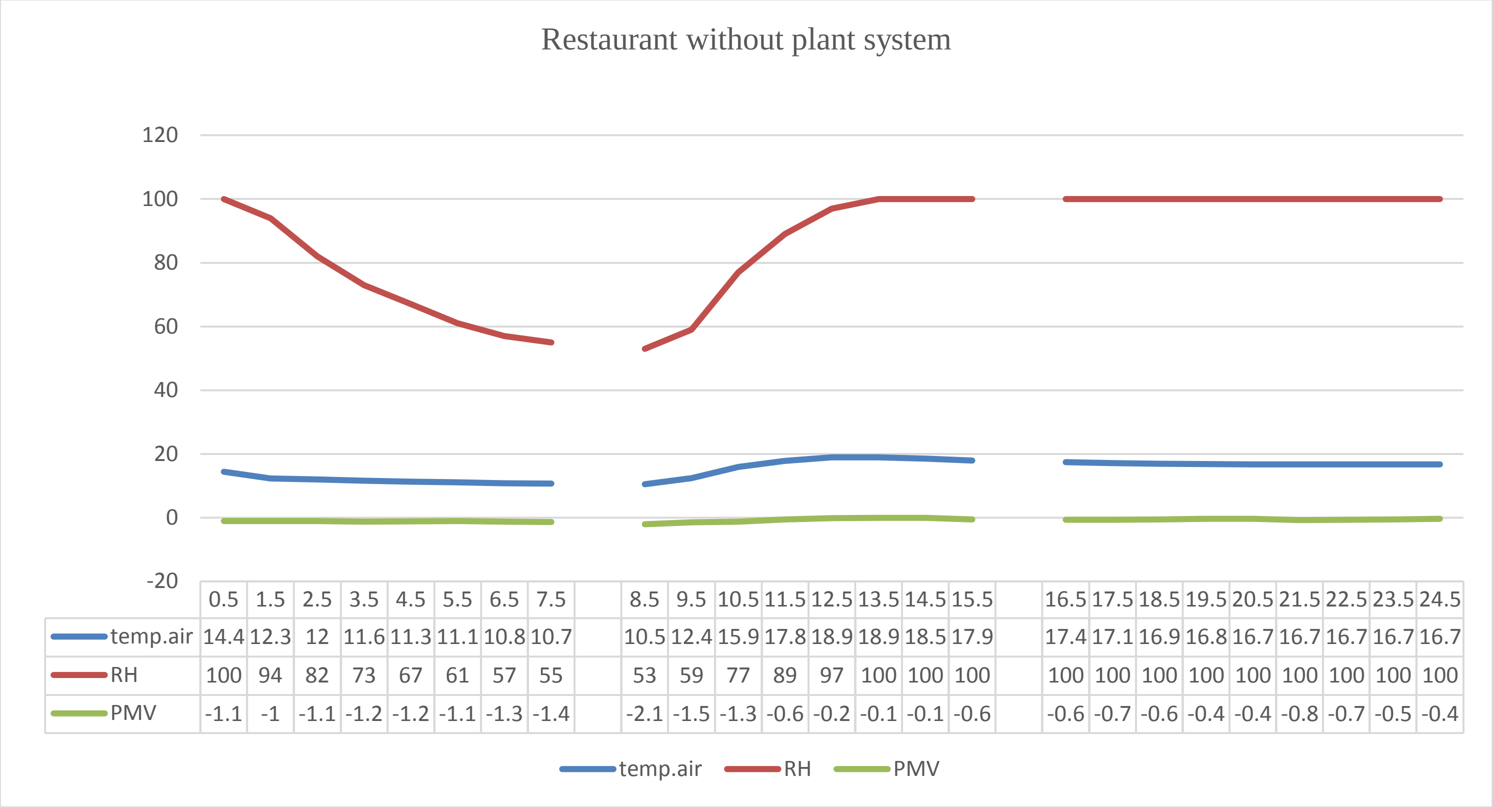
Where,

- M denotes metabolic rates
- L represents the thermal load, which is the difference between the internal heat production and heat loss to the actual environment for a person hypothetically kept at comfort values of skin temperature and evaporative heat loss by sweating at the actual activity level.

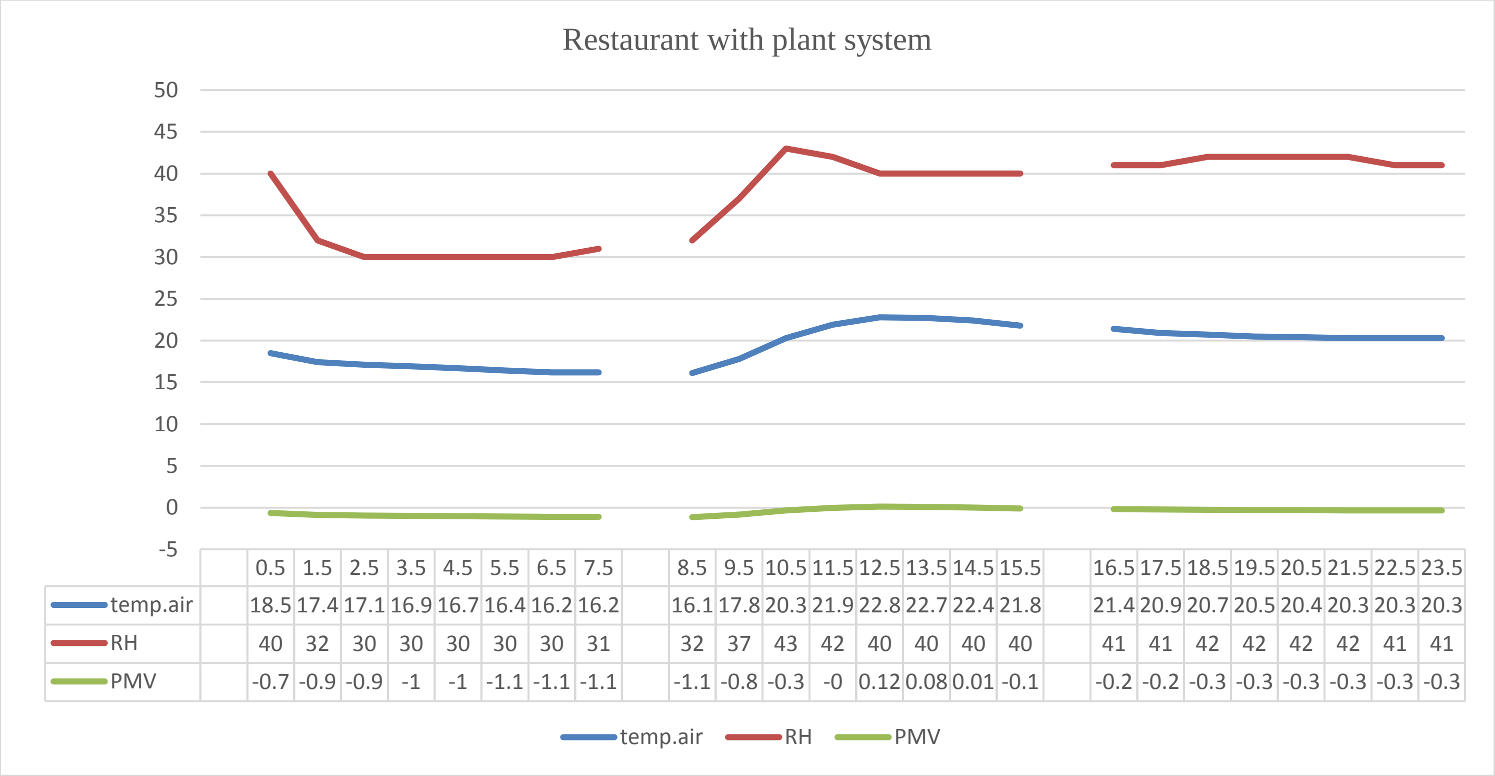
Based on the above expression, comparison of indoor comfort is carried out for one day. This involves two high occupancy zones in ground floor and two zones in bedroom at two different climate seasons for a model with plant system and model without plant system. The thermal comfort of the remaining plant connected zones are shown in Appendix-B.

Winter season- A model without plant system and with plant system

Restaurant



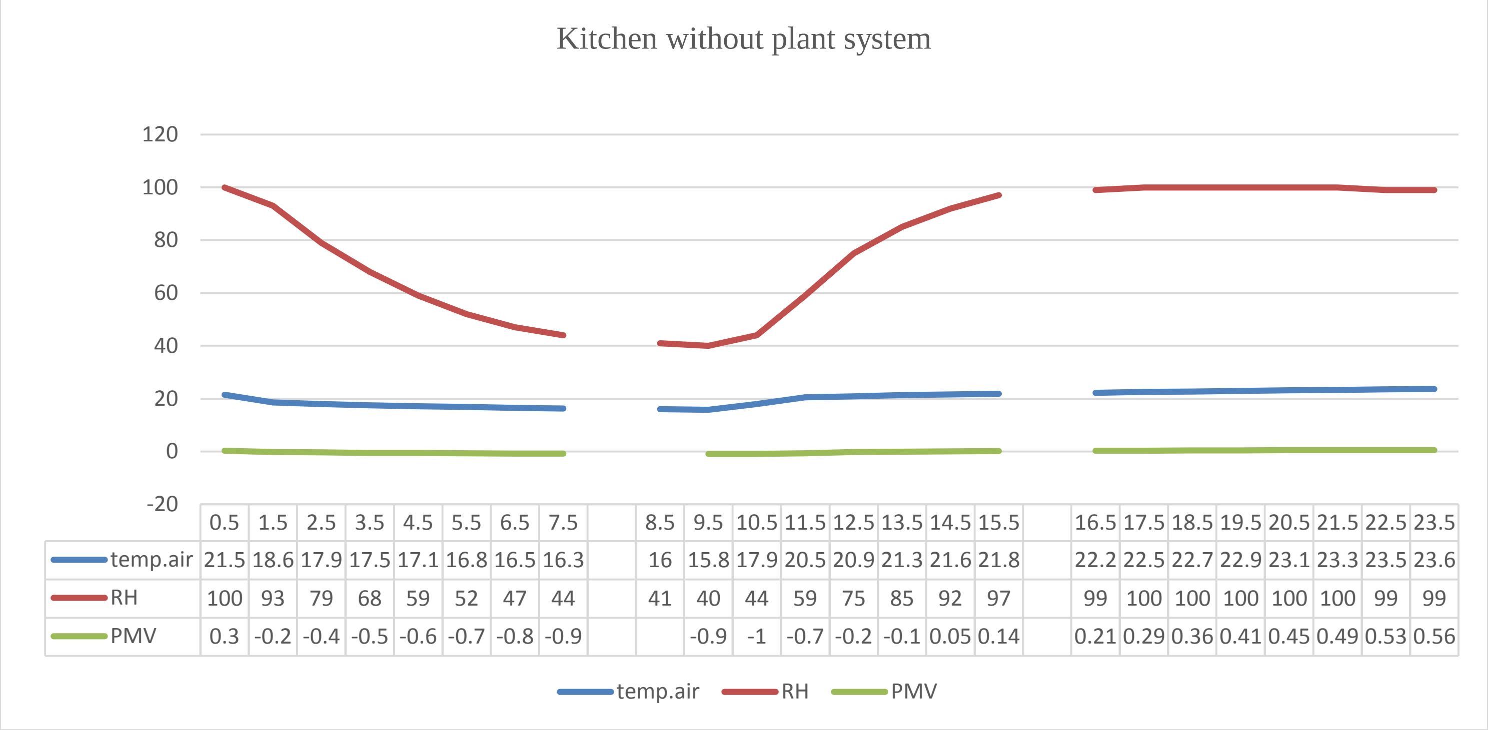
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5
temp.air	14.4	12.3	12	11.6	11.3	11.1	10.8	10.7		10.5	12.4	15.9	17.8	18.9	18.9	18.5	17.9		17.4	17.1	16.9	16.8	16.7	16.7	16.7	16.7	16.7
RH	100	94	82	73	67	61	57	55		53	59	77	89	97	100	100	100		100	100	100	100	100	100	100	100	100
PMV	-1.1	-1	-1.1	-1.2	-1.2	-1.1	-1.3	-1.4		-2.1	-1.5	-1.3	-0.6	-0.2	-0.1	-0.1	-0.6		-0.6	-0.7	-0.6	-0.4	-0.4	-0.8	-0.7	-0.5	-0.4



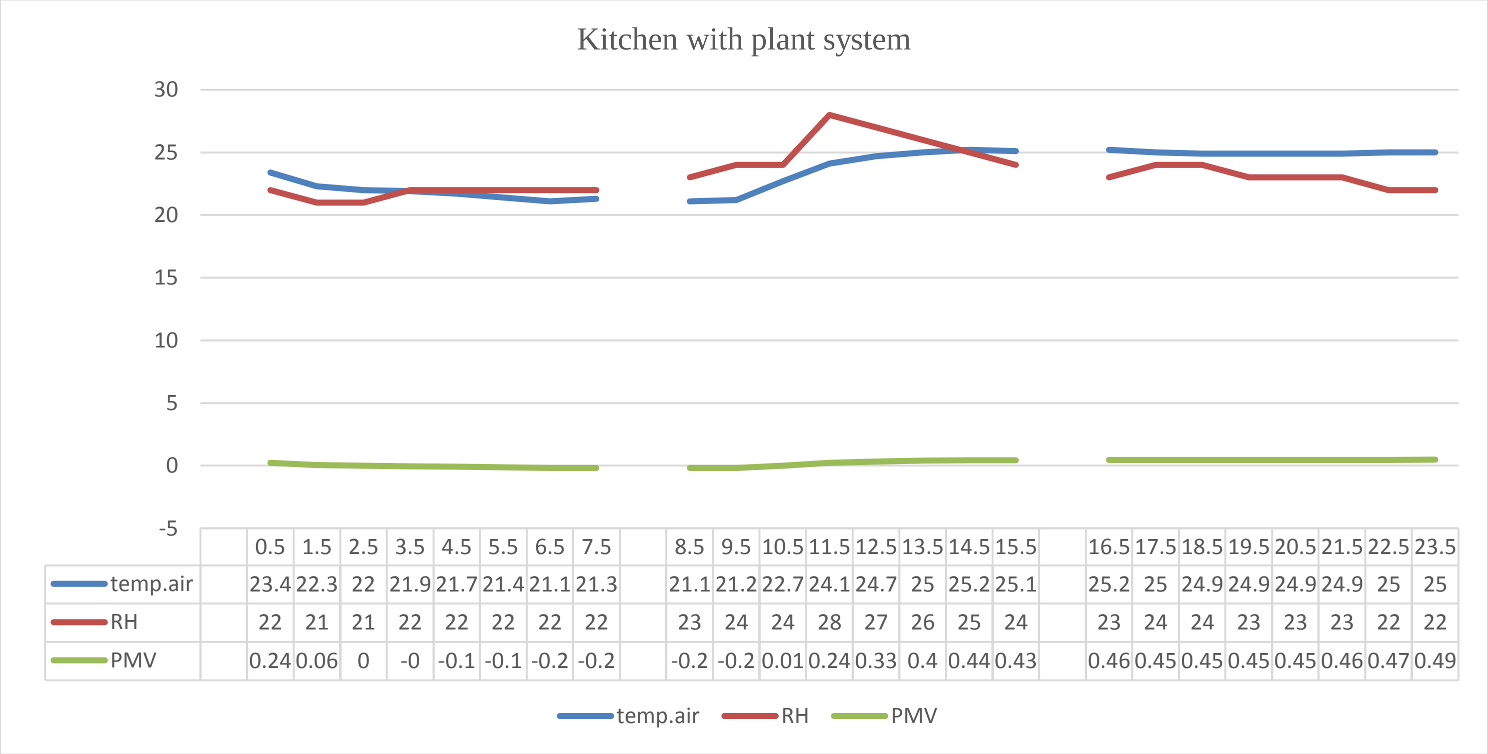
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air		18.5	17.4	17.1	16.9	16.7	16.4	16.2	16.2		16.1	17.8	20.3	21.9	22.8	22.7	22.4	21.8		21.4	20.9	20.7	20.5	20.4	20.3	20.3	20.3
RH		40	32	30	30	30	30	30	31		32	37	43	42	40	40	40	40		41	41	42	42	42	42	41	41
PMV		-0.7	-0.9	-0.9	-1	-1	-1.1	-1.1	-1.1		-1.1	-0.8	-0.3	-0	0.12	0.08	0.01	-0.1		-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3

Figure 87: Indoor air comfort of restaurant

Kitchen


Kitchen without plant system

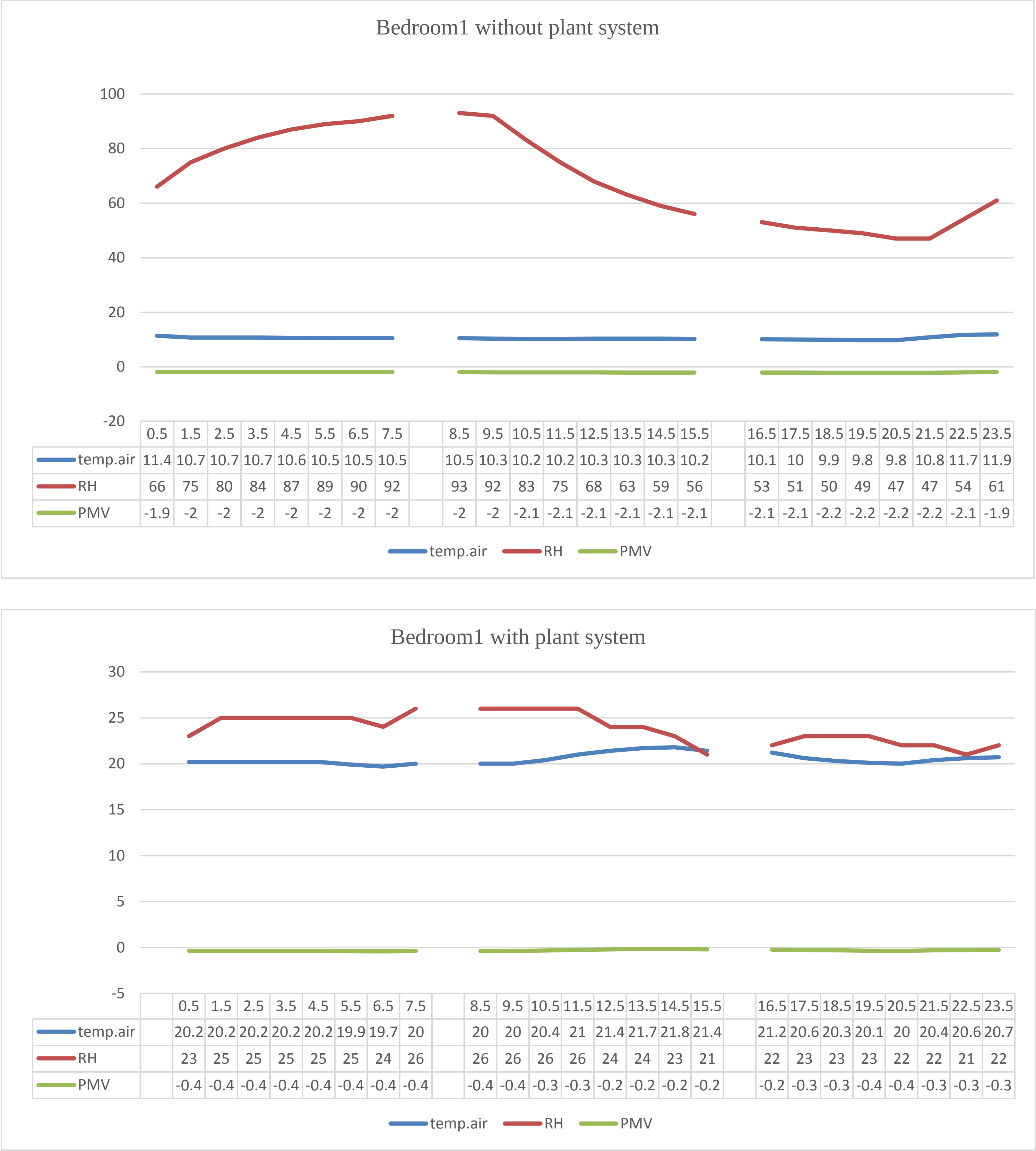
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	21.5	18.6	17.9	17.5	17.1	16.8	16.5	16.3		16	15.8	17.9	20.5	20.9	21.3	21.6	21.8		22.2	22.5	22.7	22.9	23.1	23.3	23.5	23.6
RH	100	93	79	68	59	52	47	44		41	40	44	59	75	85	92	97		99	100	100	100	100	100	99	99
PMV	0.3	-0.2	-0.4	-0.5	-0.6	-0.7	-0.8	-0.9			-0.9	-1	-0.7	-0.2	-0.1	0.05	0.14		0.21	0.29	0.36	0.41	0.45	0.49	0.53	0.56


Kitchen with plant system

		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air		23.4	22.3	22	21.9	21.7	21.4	21.1	21.3		21.1	21.2	22.7	24.1	24.7	25	25.2	25.1		25.2	25	24.9	24.9	24.9	24.9	25	25
RH		22	21	21	22	22	22	22	22		23	24	24	28	27	26	25	24		23	24	24	23	23	23	22	22
PMV		0.24	0.06	0	-0	-0.1	-0.1	-0.2	-0.2		-0.2	-0.2	0.01	0.24	0.33	0.4	0.44	0.43		0.46	0.45	0.45	0.45	0.45	0.46	0.47	0.49

Figure 88: Indoor air comfort of kitchen

Bedroom1

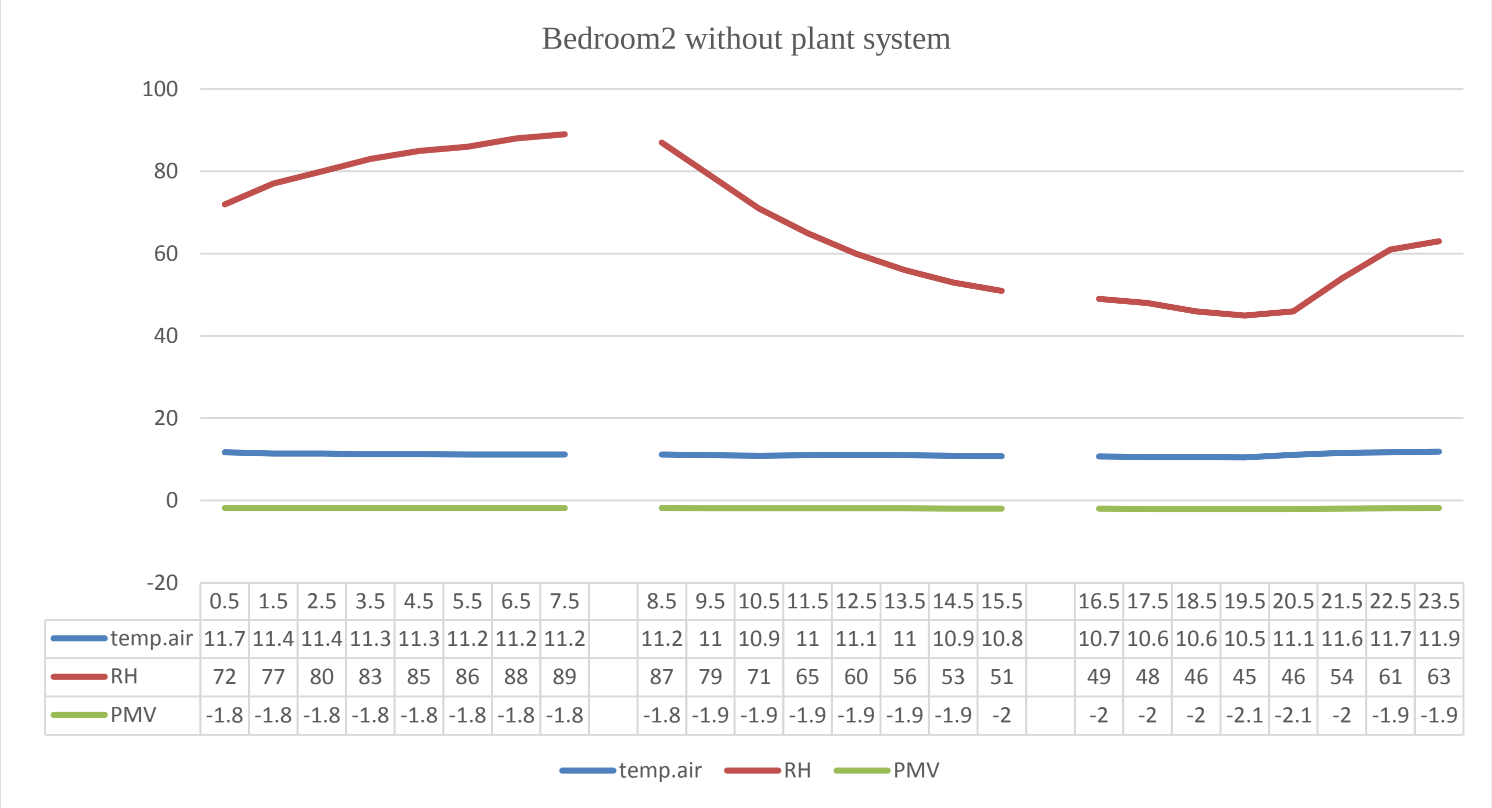


	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	11.4	10.7	10.7	10.7	10.6	10.5	10.5	10.5		10.5	10.3	10.2	10.2	10.3	10.3	10.3	10.2		10.1	10	9.9	9.8	9.8	10.8	11.7	11.9
RH	66	75	80	84	87	89	90	92		93	92	83	75	68	63	59	56		53	51	50	49	47	47	54	61
PMV	-1.9	-2	-2	-2	-2	-2	-2	-2		-2	-2	-2.1	-2.1	-2.1	-2.1	-2.1	-2.1		-2.1	-2.1	-2.2	-2.2	-2.2	-2.2	-2.1	-1.9

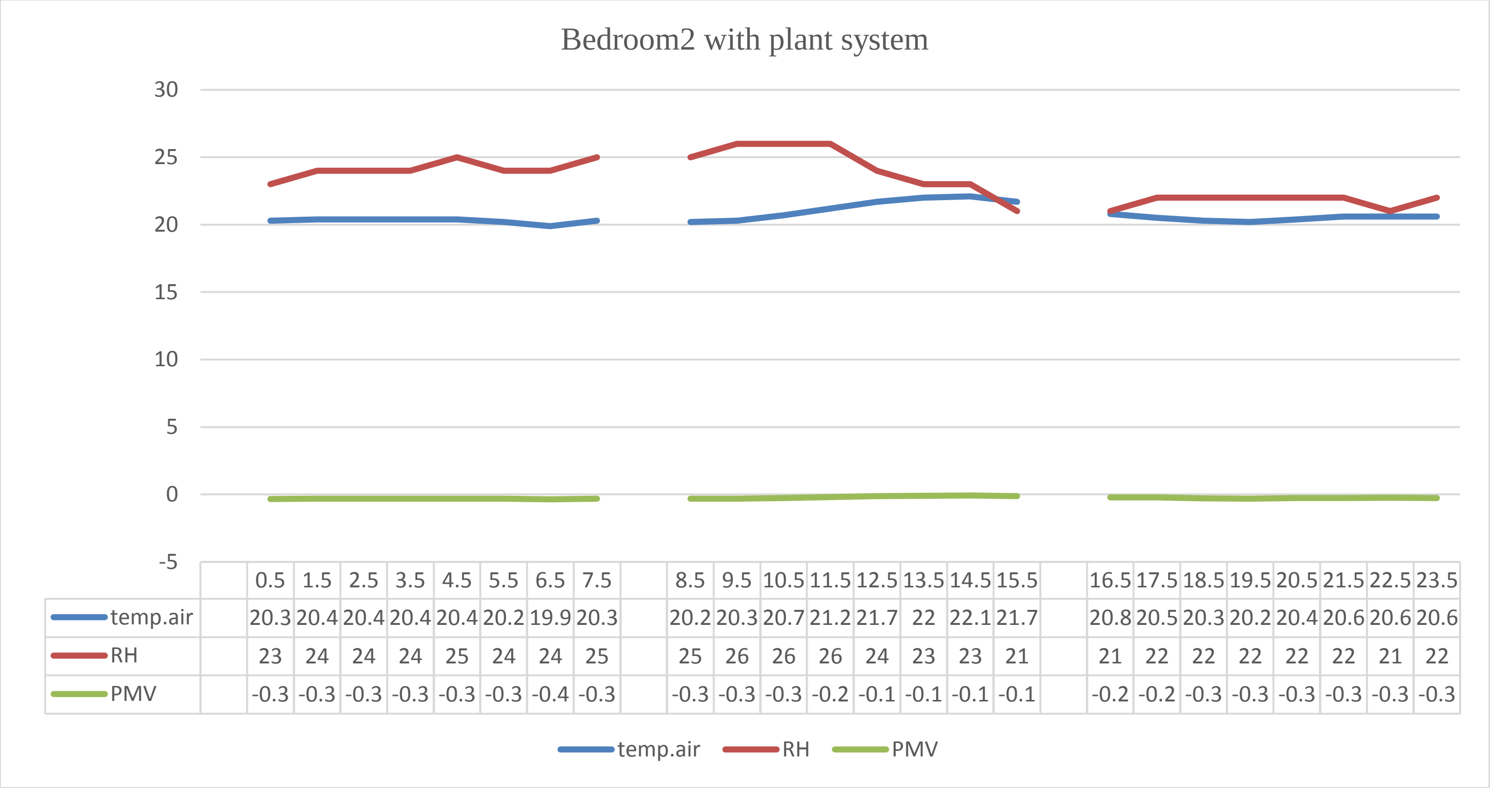
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air		20.2	20.2	20.2	20.2	20.2	19.9	19.7	20		20	20	20.4	21	21.4	21.7	21.8	21.4		21.2	20.6	20.3	20.1	20	20.4	20.6	20.7
RH		23	25	25	25	25	25	24	26		26	26	26	26	24	24	23	21		22	23	23	23	22	22	21	22
PMV		-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4		-0.4	-0.4	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2		-0.2	-0.3	-0.3	-0.4	-0.4	-0.3	-0.3	-0.3

Figure 89: Indoor air comfort of bedroom1

Bedroom2



	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	11.7	11.4	11.4	11.3	11.3	11.2	11.2	11.2		11.2	11	10.9	11	11.1	11	10.9	10.8		10.7	10.6	10.6	10.5	11.1	11.6	11.7	11.9
RH	72	77	80	83	85	86	88	89		87	79	71	65	60	56	53	51		49	48	46	45	46	54	61	63
PMV	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8		-1.8	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-2		-2	-2	-2	-2.1	-2.1	-2	-1.9	-1.9

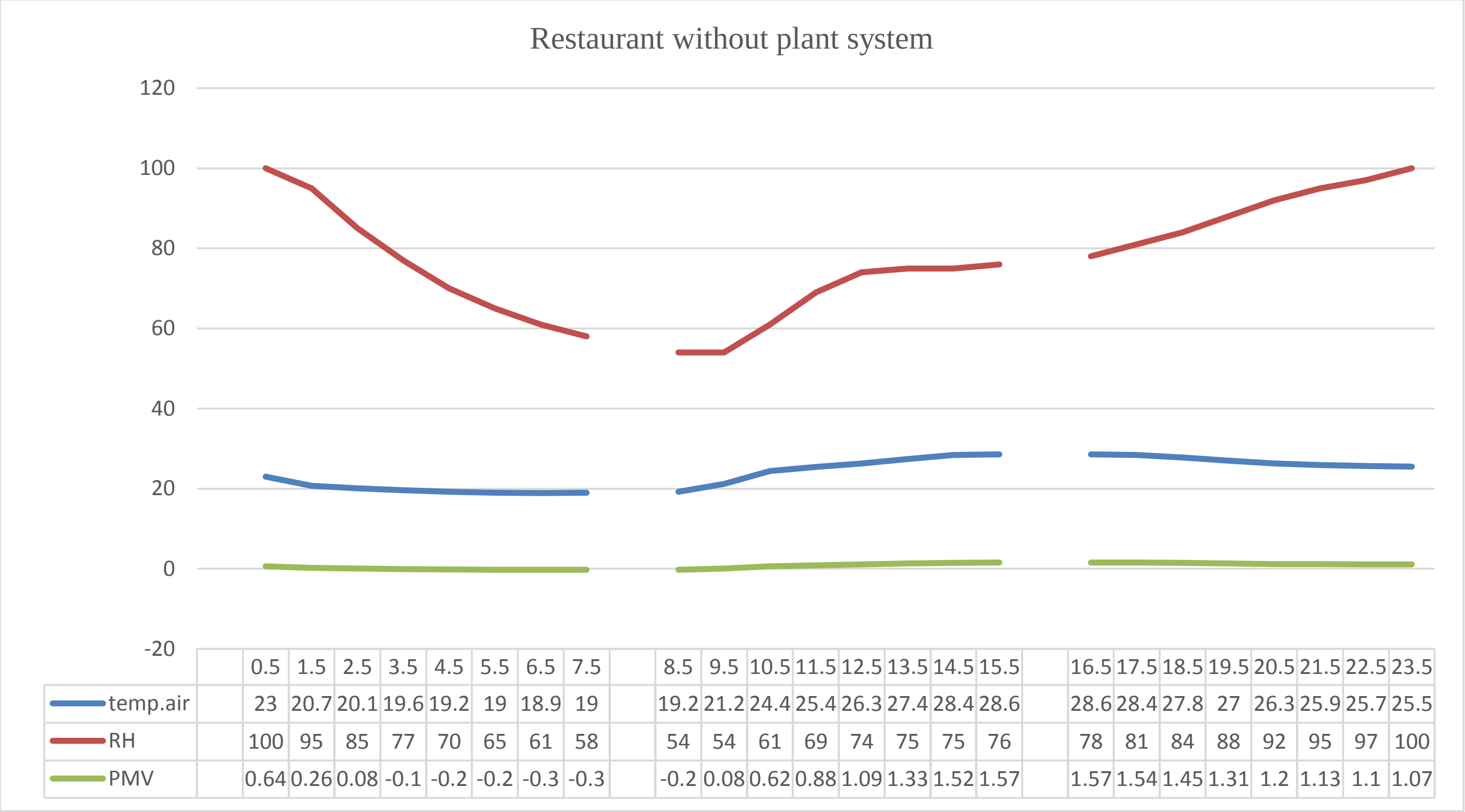


	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	20.3	20.4	20.4	20.4	20.4	20.2	19.9	20.3		20.2	20.3	20.7	21.2	21.7	22	22.1	21.7		20.8	20.5	20.3	20.2	20.4	20.6	20.6	20.6
RH	23	24	24	24	25	24	24	25		25	26	26	26	24	23	23	21		21	22	22	22	22	22	21	22
PMV	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3		-0.3	-0.3	-0.3	-0.2	-0.1	-0.1	-0.1	-0.1		-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3

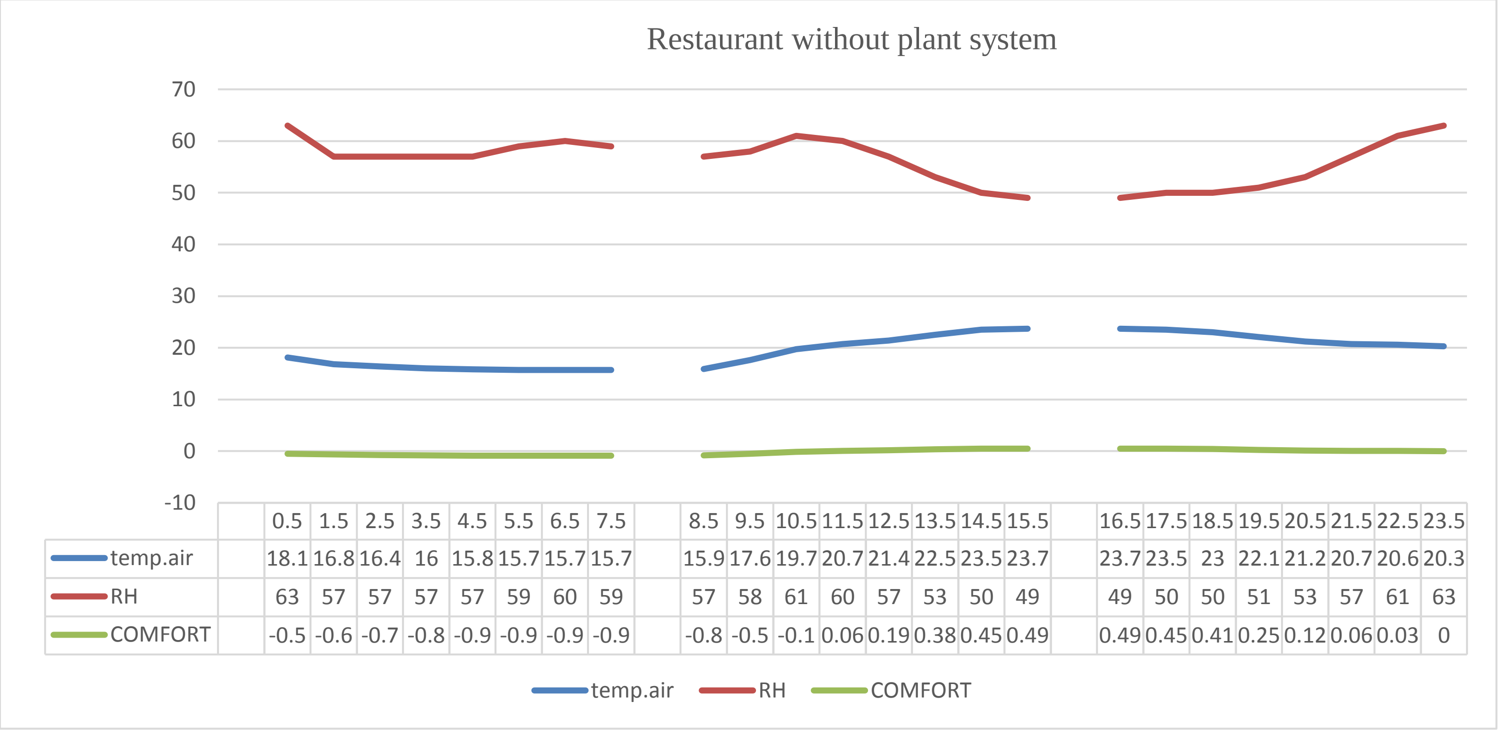
Figure 90: Indoor air comfort of bedroom2

Summer season- A model without plant system and with plant system

<u>Restaurant</u>



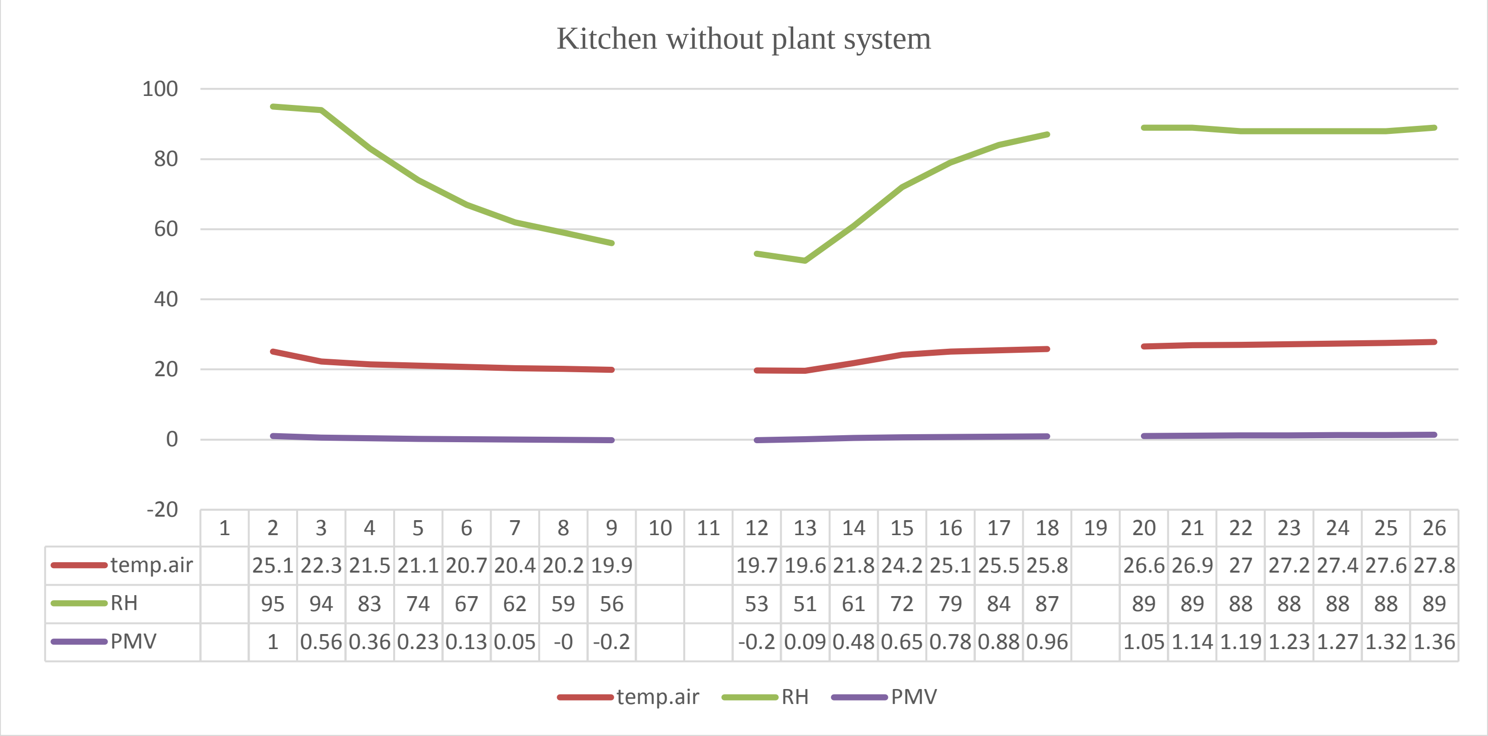
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	23	20.7	20.1	19.6	19.2	19	18.9	19		19.2	21.2	24.4	25.4	26.3	27.4	28.4	28.6		28.6	28.4	27.8	27	26.3	25.9	25.7	25.5
RH	100	95	85	77	70	65	61	58		54	54	61	69	74	75	75	76		78	81	84	88	92	95	97	100
PMV	0.64	0.26	0.08	-0.1	-0.2	-0.2	-0.3	-0.3		-0.2	0.08	0.62	0.88	1.09	1.33	1.52	1.57		1.57	1.54	1.45	1.31	1.2	1.13	1.1	1.07



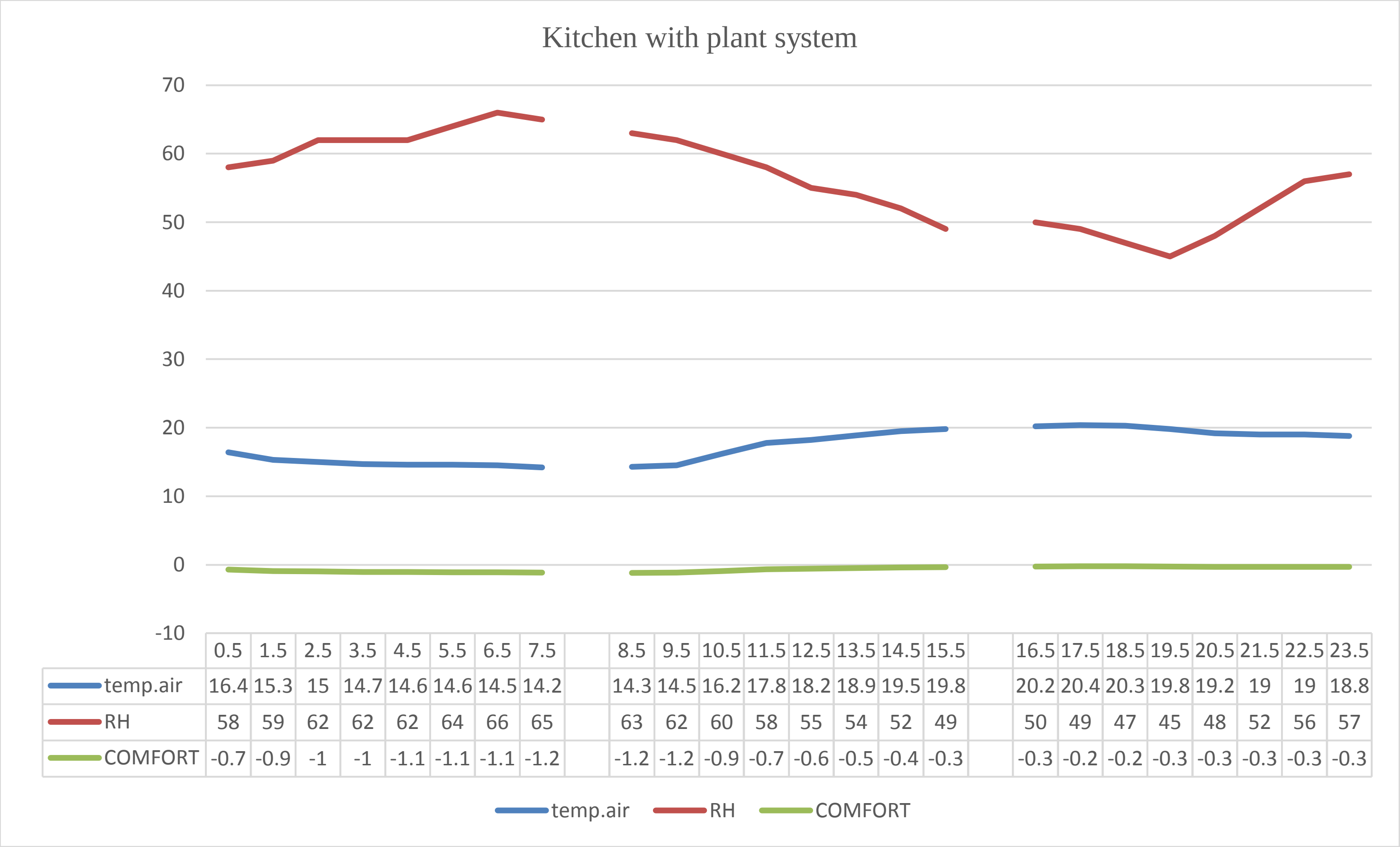
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	18.1	16.8	16.4	16	15.8	15.7	15.7	15.7		15.9	17.6	19.7	20.7	21.4	22.5	23.5	23.7		23.7	23.5	23	22.1	21.2	20.7	20.6	20.3
RH	63	57	57	57	57	59	60	59		57	58	61	60	57	53	50	49		49	50	50	51	53	57	61	63
COMFORT	-0.5	-0.6	-0.7	-0.8	-0.9	-0.9	-0.9	-0.9		-0.8	-0.5	-0.1	0.06	0.19	0.38	0.45	0.49		0.49	0.45	0.41	0.25	0.12	0.06	0.03	0

Figure 91: Indoor air comfort of restaurant

Kitchen



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
temp.air		25.1	22.3	21.5	21.1	20.7	20.4	20.2	19.9			19.7	19.6	21.8	24.2	25.1	25.5	25.8		26.6	26.9	27	27.2	27.4	27.6	27.8
RH		95	94	83	74	67	62	59	56			53	51	61	72	79	84	87		89	89	88	88	88	88	89
PMV		1	0.56	0.36	0.23	0.13	0.05	-0	-0.2			-0.2	0.09	0.48	0.65	0.78	0.88	0.96		1.05	1.14	1.19	1.23	1.27	1.32	1.36



	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	16.4	15.3	15	14.7	14.6	14.6	14.5	14.2		14.3	14.5	16.2	17.8	18.2	18.9	19.5	19.8		20.2	20.4	20.3	19.8	19.2	19	19	18.8
RH	58	59	62	62	62	64	66	65		63	62	60	58	55	54	52	49		50	49	47	45	48	52	56	57
COMFORT	-0.7	-0.9	-1	-1	-1.1	-1.1	-1.1	-1.2		-1.2	-1.2	-0.9	-0.7	-0.6	-0.5	-0.4	-0.3		-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3

Figure 92: Indoor air comfort of kitchen

9.4 ENERGY ANALYSIS

The following graph and table are an outcome of the comparison of energy performance of the building with energy benchmark

SOURCE	Energy Consumption in kWh/m2
Electricity	212.8709597
CIBSE benchmark	105

Table 12: Annual electricity consumption comparison

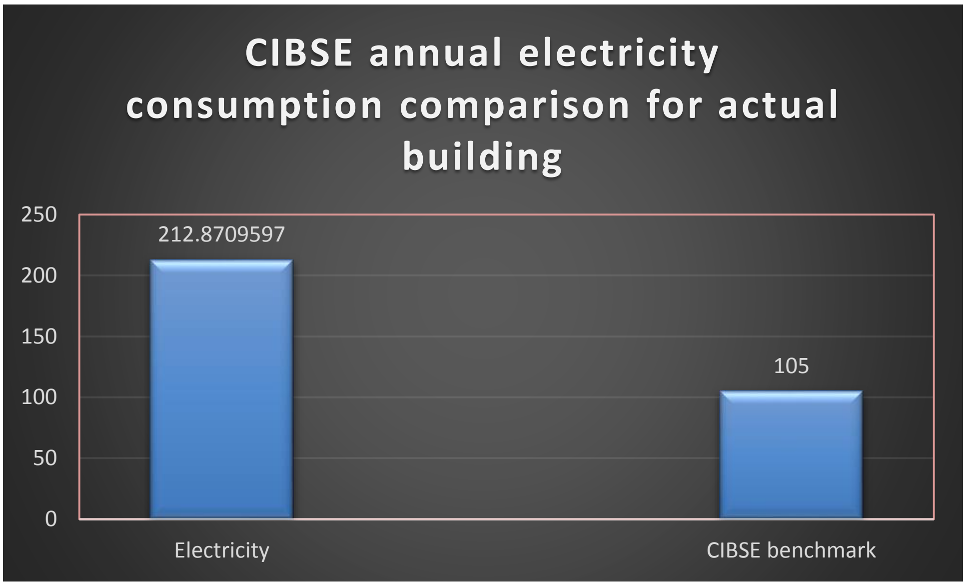


Figure 93: Annual electricity consumption comparison

Source	CO2 emission in kgCO2/m2
Electricity	89.83154499
CIBSE benchmark	57.8

Table 13: Annual CO2 Emission comparison

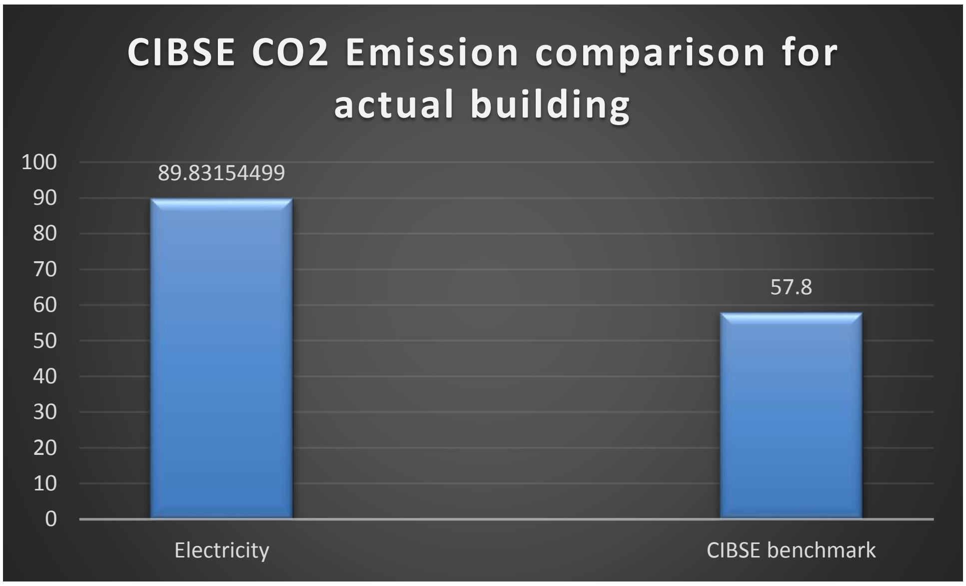


Figure 94: Annual CO2 Emission comparison

SOURCE	Energy Consumption in kWh/m2
L.P.G	293.9078282
CIBSE benchmark	330

Table 14: Annual CO2 Emission comparison

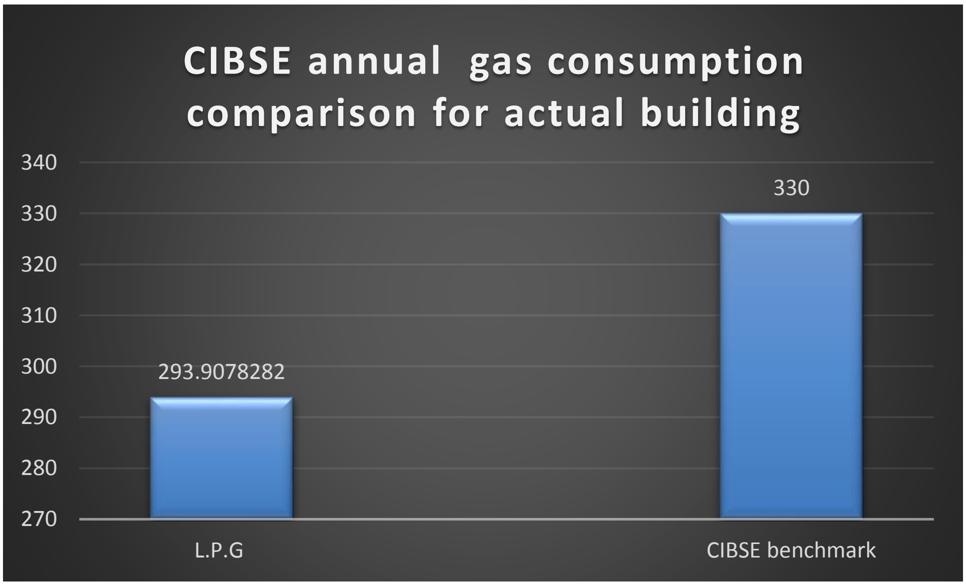


Figure 95: Annual gas consumption comparison

Source	CO2 emission in kgCO2/m2
L.P.G	68.7744318
CIBSE benchmark	62.7

Table 15: Annual CO2 Emission comparison

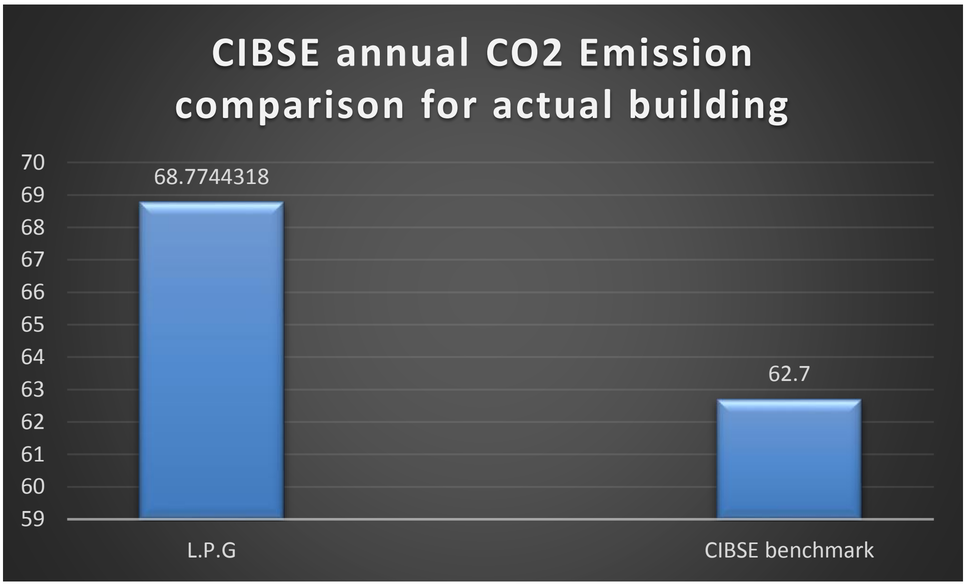


Figure 96: Annual CO2 Emission comparison

ENERGY COMPARISON

The figure: 97 represents the energy consumption by MVHR system if installed for whole building

MVHR model Energy delivered					
		kWhr			no. of rooms
	TOP FLOOR	4153			116
	GROUND FLOOR	4513.3			
			top floor consumption	34410.57143	
			total consumption	**38923.87143**	

Figure 97: Energy delivered

The energy delivered result obtained from the simulation was shown in the table 16

Zone	Sensible heating		Sensible cooling		Humidification		Dehumidification	
id name	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd	Energy (kWhrs)	No. of Hr rqd
1 RT	1410.02	744.0	0.00	0.0	0.00	0.0	0.00	0.0
2 KN	370.28	629.0	-21.50	115.0	0.00	0.0	0.00	0.0
3 SCN	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
4 PR	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
5 SR	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
6 MR1	866.63	739.0	-0.73	5.0	0.00	0.0	0.00	0.0
7 MR2	554.07	740.0	-0.53	4.0	0.00	0.0	0.00	0.0
8 SS	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
9 OE	210.94	731.0	-0.67	13.0	0.00	0.0	0.00	0.0
10 SE	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
11 PY1	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
12 PY2	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
13 LY	1101.36	744.0	0.00	0.0	0.00	0.0	0.00	0.0
14 b1	214.38	731.0	-0.80	13.0	0.00	0.0	0.00	0.0
15 b2	171.09	721.0	-1.33	23.0	0.00	0.0	0.00	0.0
16 b3	171.87	721.0	-1.31	23.0	0.00	0.0	0.00	0.0
17 b5	198.84	731.0	-0.72	13.0	0.00	0.0	0.00	0.0
18 b6	120.71	686.0	-4.49	58.0	0.00	0.0	0.00	0.0
19 b7	118.89	681.0	-4.74	63.0	0.00	0.0	0.00	0.0
20 b8	155.78	728.0	-0.57	16.0	0.00	0.0	0.00	0.0
21 US	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
22 M1	388.57	736.0	-0.70	8.0	0.00	0.0	0.00	0.0
23 m2	393.57	736.0	-0.64	8.0	0.00	0.0	0.00	0.0
24 sb1	254.97	737.0	-0.18	7.0	0.00	0.0	0.00	0.0
25 m3	472.07	740.0	-0.22	4.0	0.00	0.0	0.00	0.0
26 sb2	323.12	743.0	-0.00	1.0	0.00	0.0	0.00	0.0
27 b4	236.87	737.0	-0.27	7.0	0.00	0.0	0.00	0.0
28 m4	932.84	744.0	0.00	0.0	0.00	0.0	0.00	0.0
29 pw3	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0

Table 16: kWhr energy delivered

This result will be elaborately discussed in analysis and discussion chapter

10 ANALYSIS AND DISCUSSION

Looking at the winter simulation results of the model (without plant system), figure49 clearly shows that for most part of the day the outside temperature of the place is within the range of 2°C to 7C. The figure49 shows during the start of the month, the temperature is at 2.5C, later there is a periodic decrease in temperature and thereby reaches the lowest temperature point of -6.4C. After this there is a gradual increase and decrease in the temperature over the next few weeks and thereby for the month of January the maximum temperature stood at around 12.7C. However during the month of January the direct normal solar intensity occurs for only 14 days and the maximum solar intensity for the month of January was 544 W/m^2. This solar intensity could be utilized to keep the zone warm by installing glazed windows.

As mentioned in the model description the restaurant and the office has double glazed windows and when simulation was carried out in ESP-r with double glazed windows the total solar radiation absorbed through the windows installed at the restaurant and office was 8167.1 W and 1002.1W respectively. This solar absorption thereby tends to increase the zone air temperature as well as the relative humidity levels compared to the zones without double glazed windows. Figure 51 to 59, shows that the decrease in temperature in turn decreases the RH level and vice versa.

Further summer simulation was performed to visualize the ambient outside temperature and the amount of solar entering the building and the intensity of absorption. Figure59 clearly shows that for most part of the day the outside temperature of the place is within the range of 9°C to 18C. The figure59 also shows during the start of the month, the temperature is at 9C, later there is a periodic decrease in temperature and thereby reaches the highest temperature point of 20.8C. After this there is a gradual increase and decrease in the temperature over the next few weeks and thereby for the month of June the minimum temperature stood at around 5C. During the month of June the direct normal solar intensity occurs for 20 days and the maximum solar intensity during the month was 766.5W/m^2. This solar intensity could be utilized to keep the zone warm by installing glazed windows.

As mentioned in the model description the restaurant and the office has double glazed windows and when simulation was carried out in ESP-r with double glazed windows the total solar radiation absorbed through the windows installed at the restaurant and office was 7804W and 762.33W respectively. This solar absorption thereby tends to increase the zone air temperature as well as the relative humidity levels compared to the zones without double glazed windows. Figure 61 to 68 shows that the decrease in temperature in turn decreases the RH level and vice versa.

In a similar way, the simulation for winter season was carried out for the model with the definition of a plant system. The results obtained showed that the maximum and the minimum temperature of the zones connected to the plant system have increased when compared with those results obtained from the model without the plant system. Along with that, the results also show that the relative humidity levels have improved and this can be seen in table9. From the figure71 it can be seen that for the entire month the RH level of the restaurant is maintained within the range of 35% to 55% when compared with RH level which was obtained for the model without the plant system (figure: 53). This relative humidity level is within the level as discussed in chapter: 5.2 which is set as a standard level which thereby helps to avoid health issues, dust mites and the mould. Similarly figure:72 shows that the when the plant system was connected to the kitchen the RH level drops to 13.23% and during the later part of the month there is periodic rise and fall in the RH level. Even though the RH level is not within the limit the thermal comfort within the zone has been improved considerably when compared with the previous model which was developed without the plant system.

Since the top floor zones like bedroom1, 2 3 and 4 are in comfort level, the plant system-2 is not connected to it. Further summer simulation was performed to visualize the maximum and the minimum temperature of the zones connected to the plant system has decreased when compared with those results obtained from the model without the plant system. Along with that the results also show that the relative humidity levels have improved and this can be seen in table11. From the figure83 it can be seen RH level of the restaurant is within the limit when compared with RH level which was obtained for the model without the plant system (figure: 58). Similarly figure: 84, 85 and 86 shows that when the plant system was connected with the kitchen, office and lobby most of the day the relative humidity level is within the minimum limit but in very few days it exceeds the maximum limit. Even though this happens the thermal comfort within the zone has been improved considerably when compared with the previous model which was developed without the plant system.

Thermal Comfort:

From the research conducted on large group of people by ASHARE a thermal sensation scale was framed. The table: 17 shows this scale

PMV	**Status**
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

Table 17: ASHARE thermal comfort table

However in ESP-r the level chosen for this assessment varies from the one laid out by ASHARE. The table: 18 shows the scale used in ESP-r

Human comfort status in negative PMV		**Human comfort status in positive PMV**	
PMV	Status	PMV	Status
-1 to -2	Cool, unpleasant	1 to 2	Warm, unpleasant
-2 to -3	Cold, shivering	2 to 3	Hot, very uncomfortable
-0.5 to -1	Slightly cool, acceptable	0.5 to 1	Slightly, warm acceptable
0 to -0.49	Comfortable, pleasant	0 to 0.49	Comfortable, pleasant

Table 18: ESP-r thermal comfort table

Figure: 87 shows the result which has been obtained from ESP-r assessment and this result are divided into three segments and each segments are in the time interval of 8 hours. Thus the obtained results are then compared with table 18 and during winter simulation in the first 8 hours of section in restaurant graph without plant system (figure: 87) shows that the comfort level for the entire section was cool, unpleasant. The first hour of the next segment is cold shivering and the next two hours it gradually comes to the level of cool unpleasant and the remaining hour of the section shows to be comfortable, pleasant. The entire final segment of the table shows that the comfort level is slightly cool, acceptable. From the figure: 87 the entire final segment of the restaurant with plant system can be termed as comfortable and pleasant for the users, whereas during the first 5 hours of segment 1 the comfort levels are considered to be slightly cool and unpleasant. The next 4 hours are considered as cold and shivering. In the following next segment the first hour seems to be cool unpleasant, then the following hour feel slightly cool and acceptable and the next 6 hours are in comfortable, pleasant level. From the following analysis it is clearly seen that when the plant system is deployed the comfort level, temperature inside the zones, humidity are much better than results obtained without plant system. The remaining zones in the section are also followed in the same manner.

Similarly during summer simulation the first hour of the section 1 in restaurant graph without plant system (figure: 91) shows that the comfort level is slightly warm and acceptable, while the remaining hours of the section was comfortable and pleasant. The first two hours of the section 2 feels to be comfortable, pleasant. The next two hours feels to be slightly warm, acceptable. Then the remaining hours of the section are warm, unpleasant. The entire final segment seems to be in the comfort level of warm unpleasant. From the figure: 71 the entire first segment of the restaurant with plant system seems to be in slightly warm, acceptable for the users, likewise the entire final segment seems to be in the comfort levels. The first two hour of the section 2 is slightly cool and acceptable. Then the next remaining hours are in comfortable and pleasant. . From the following analysis it is clearly seen that when the plant system is deployed the comfort level, temperature inside the zones, humidity are much better than results obtained without plant system The remaining zones in the section are also followed in the same manner.

Energy Performance Comparison

As shown in figure93 the electricity consumption (2012) comparison with the CIBSE benchmark shows that the value exceeds the benchmark by 100kWh/m2 and figure94 shows that the corresponding CO2 emission exceeds the benchmark by 30kgCO2/m2. Similarly figure95 shows that the gas consumption for the year 2012 is within the CIBSE benchmark and figure96 shows that the corresponding CO2 emission level from gas consumption exceeds the benchmark by 5kgCO2/m2. When looking at the hotel from a broader perspective, certain improvements are necessary to reduce this energy consumption.

In the ground floor the plant system is connected to 6 zones from the previous 4 zone connection strategy and the corresponding energy delivered was measured as 4513kWh. Similarly, the plant system was connected to 14 zones in the first floor from the previous 4 zone connection and the corresponding energy delivered was measured as 4153kWh. From figure: 48 it is seen that during the month of January the total consumption for the entire hotel (4 floors) is 51257kWh. Similarly from figure: 97 it is seen that during the month of January the total consumption is 38927kWh and this consumption is after the installation of the MVHR system. Moreover when looking at the two values, there is a difference of approximately 13000kWh and if lights, equipment’s and other systems are expected to consume around 10000kWh an energy saving of around 3000kWh is foreseeable when the MVHR system is installed and henceforth it is recommended to install the MVHR system in the building.

CONCLUSION

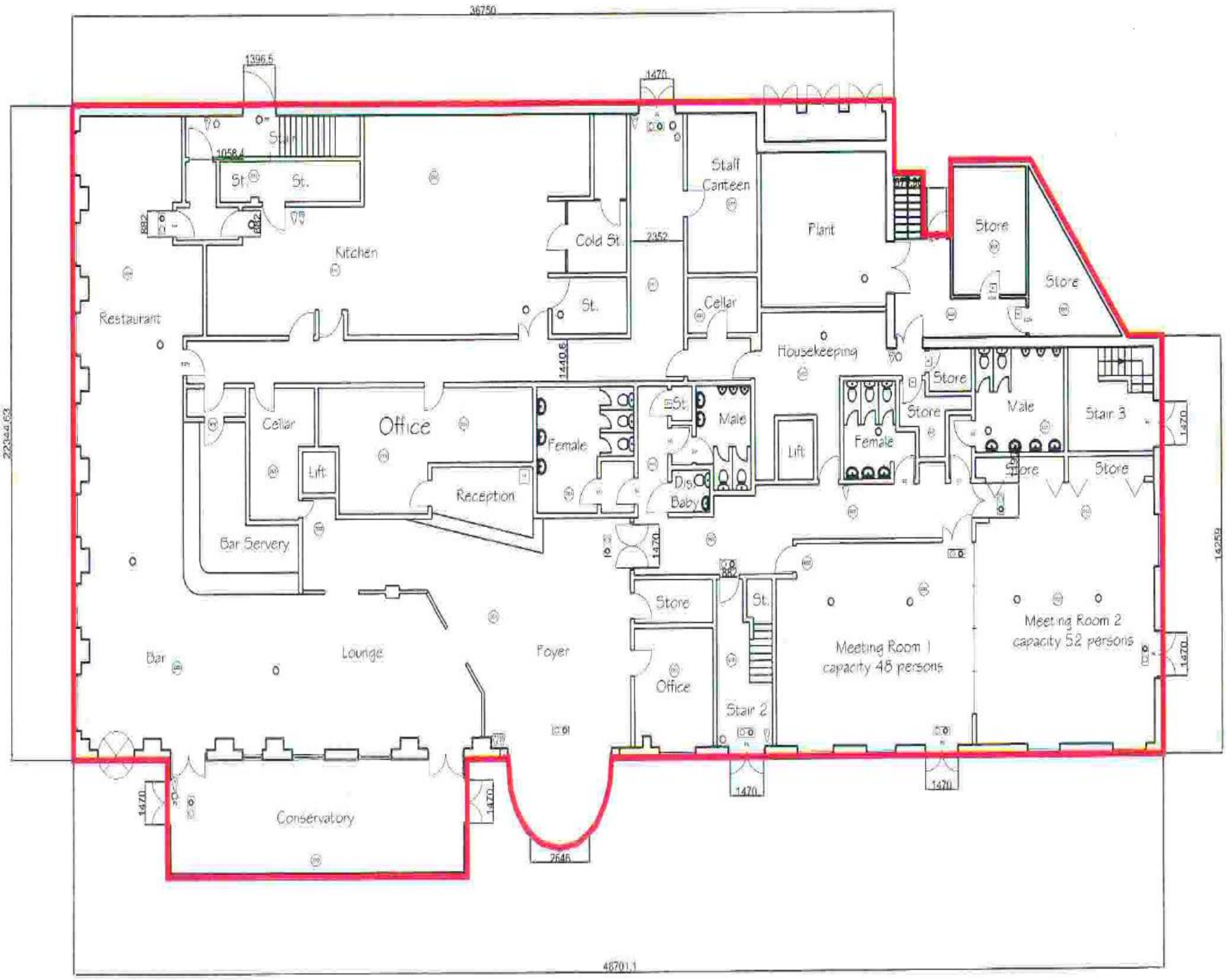
Aim of the project focuses on the improvement of internal temperature, relative humidity and final guide to thermal comfort inside the hotel sector .The existing hotel, Holiday Inn has not been installed with mechanical ventilation heat recovery system, therefore deployment of mechanical heat recovery system in dynamic simulation model; ESP-r is necessary to make a realistic approach. This suggests that the installation has improved the energy consumption and thermal comfort. When the MVHR is installed in the dynamic simulation model, the result obtained clearly shows an improvement in thermal comfort and drastic reduction in energy consumption. However, there are some practical difficulties such as: relative humidity decreases than the bench mark level during the simulation in ESP-r, but in reality it can be avoided by using humidity control. Summer simulation was performed with replacing the summer bypass mode in MVHR to cooling coil in order to provide thermal comfort inside the zones of the developed model. When the MVHR is compared to the air-conditioning unit installed in the holiday inn then according to the results the MVHR has provided with better results with respect to thermal comfort. So as a result the installation of MVHR in holiday inn is benefited with less energy consumption by the building as well as improved on the comfort level of the occupants in the building. The installation cost is always an important factor to be considered when using MVHR as compared to the air-conditioning unit.

Recommendations

- The humidity control can be used in MVHR to improve the overall humidity within the zones in the model.
- MVHR should be installed in all zones in order to get more realistic results.
- MVHR should be included within a closed place so that heat loss is controlled more effectively.
- Retrofitting the MVHR is relay high in terms of cost so proper planning during the construction stage is always necessary.

APPENDIX-A

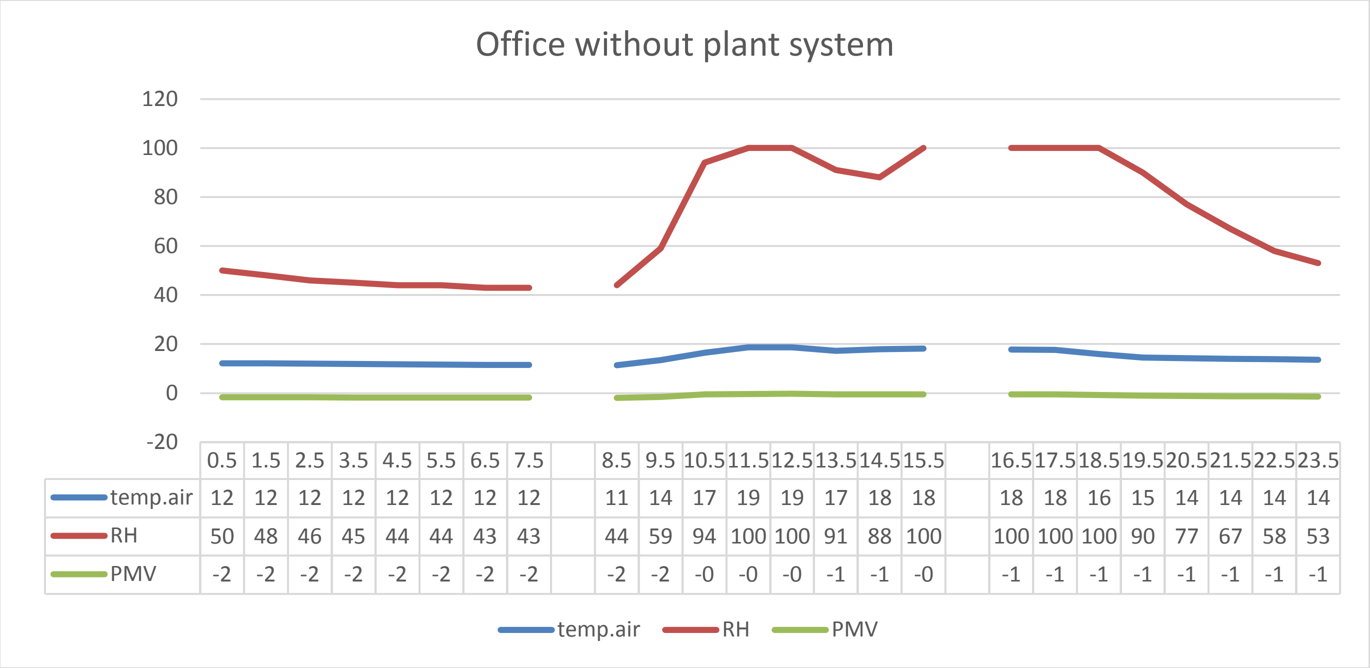
GROUND FLOOR PLAN



FIRST FLOOR PLAN

APPENDIX-B

WINTER SIMULATION- THERMAL COMFORT GRAPHS



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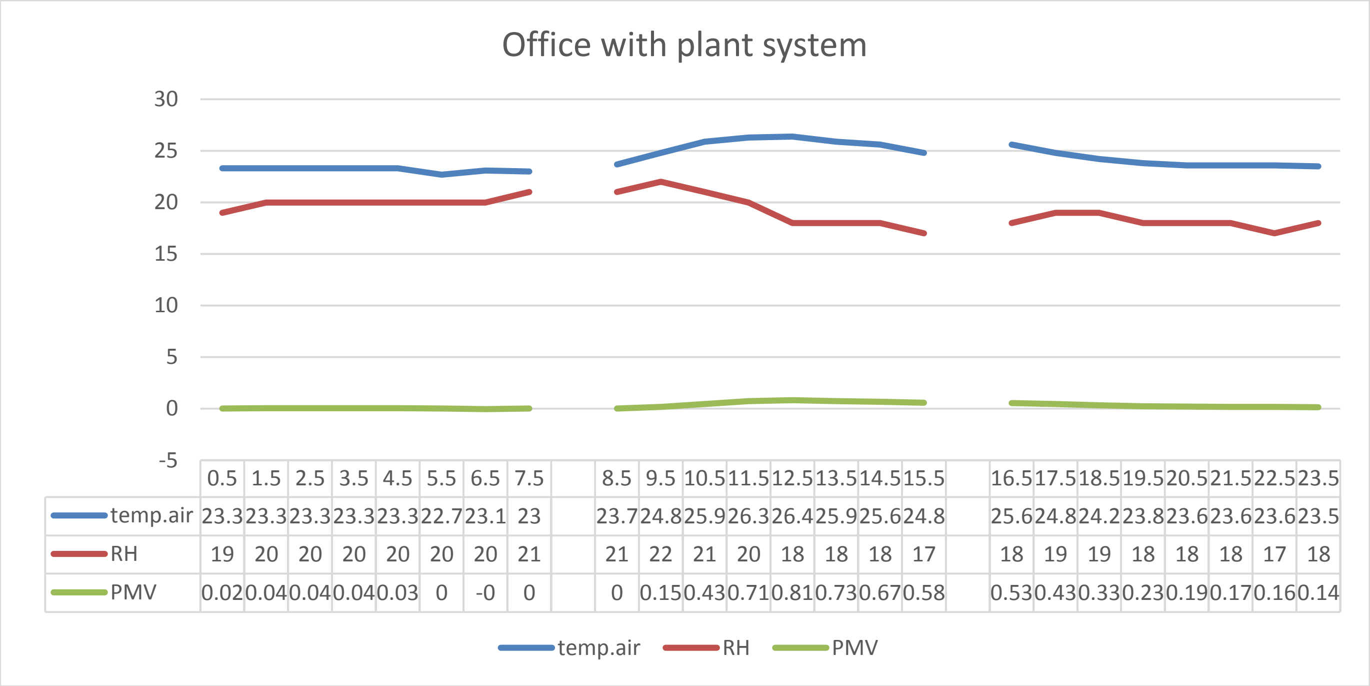
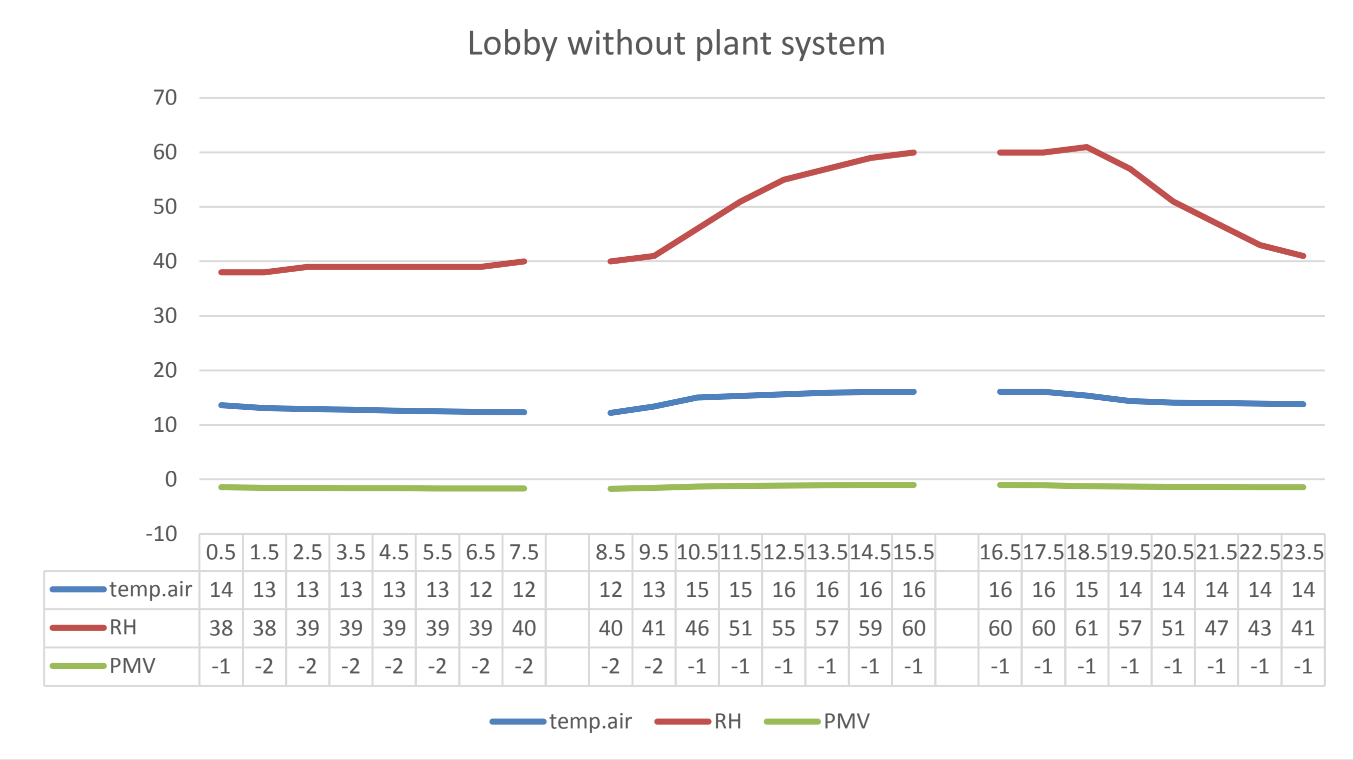
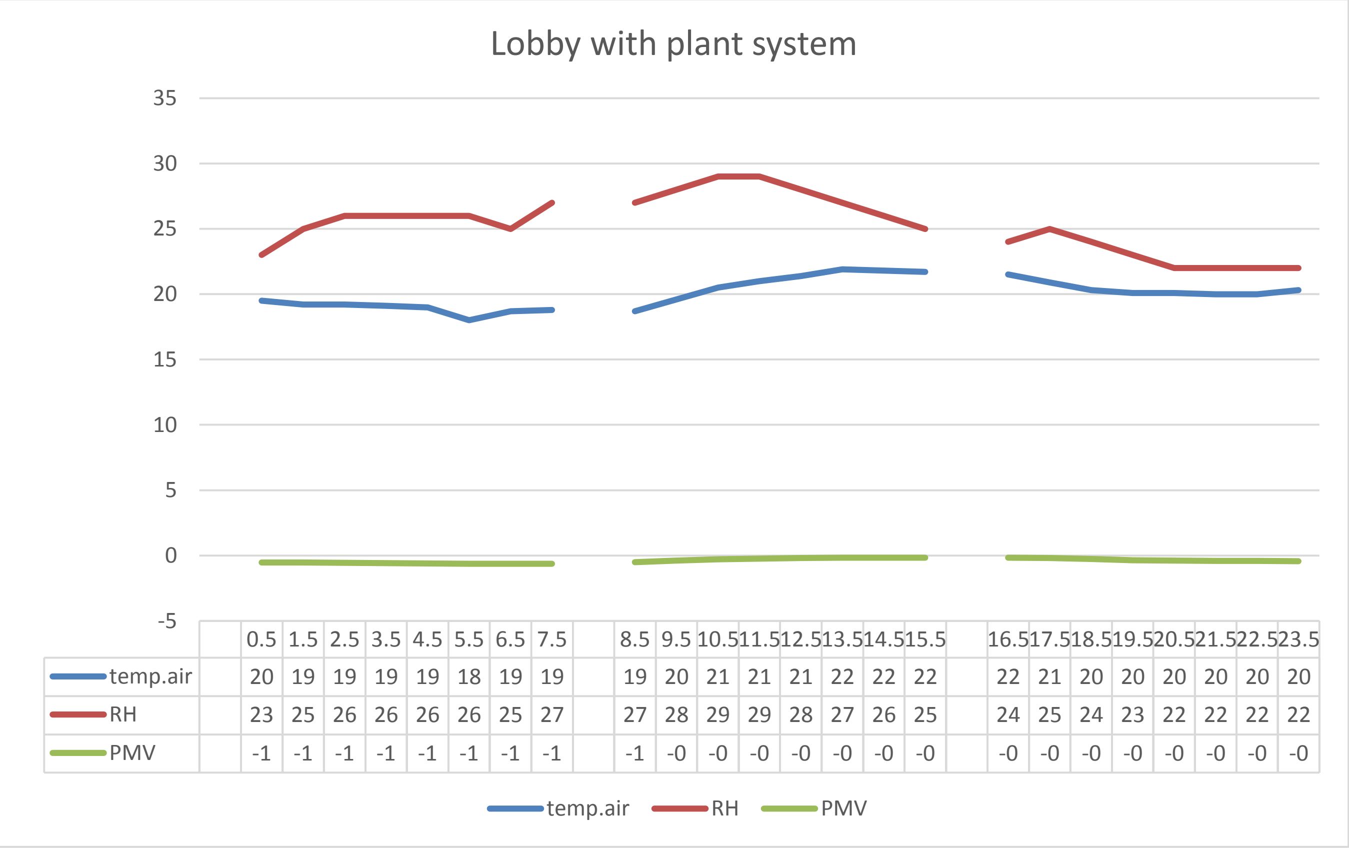
temp.air	12	12	12	12	12	12	12	12		11	14	17	19	19	17	18	18		18	18	16	15	14	14	14	14
RH	50	48	46	45	44	44	43	43		44	59	94	100	100	91	88	100		100	100	100	90	77	67	58	53
PMV	-2	-2	-2	-2	-2	-2	-2	-2		-2	-2	-0	-0	-0	-1	-1	-0		-1	-1	-1	-1	-1	-1	-1	-1



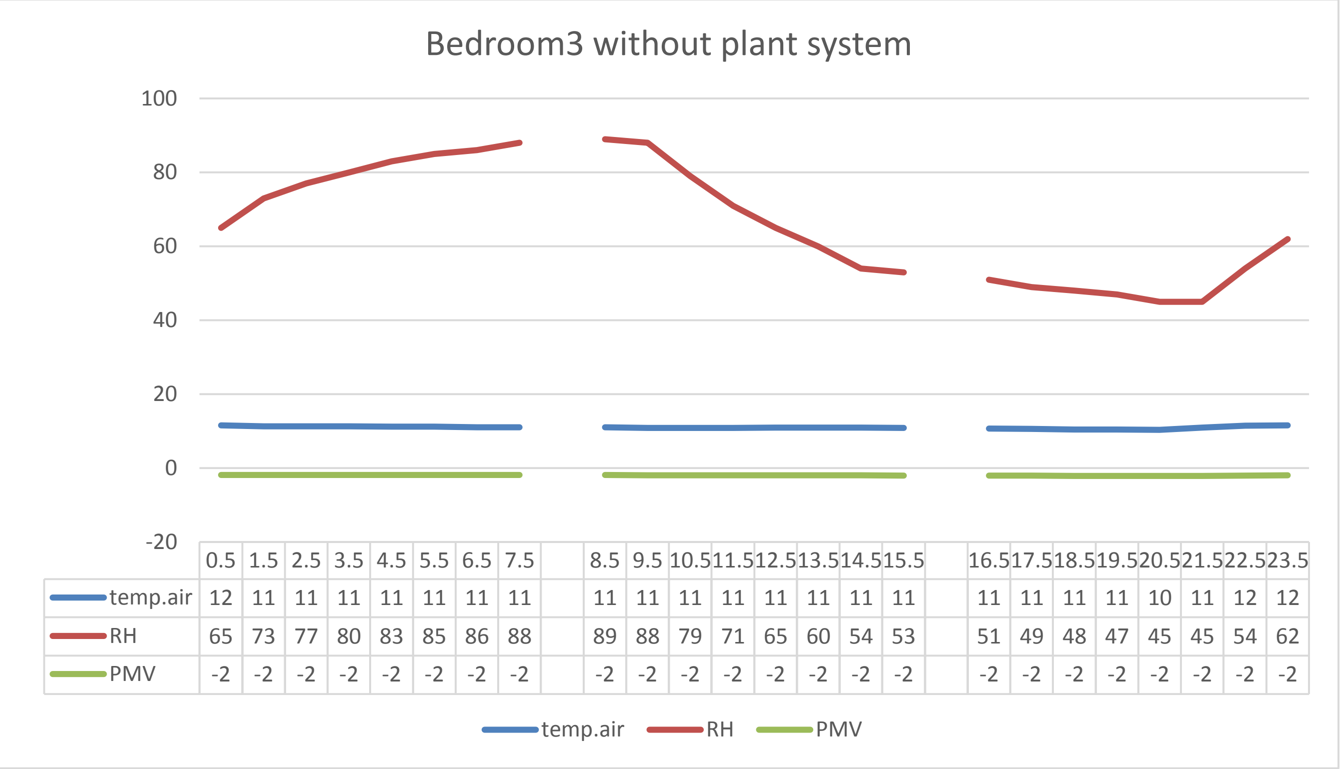
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	23.3	23.3	23.3	23.3	23.3	22.7	23.1	23		23.7	24.8	25.9	26.3	26.4	25.9	25.6	24.8		25.6	24.8	24.2	23.8	23.6	23.6	23.6	23.5
RH	19	20	20	20	20	20	20	21		21	22	21	20	18	18	18	17		18	19	19	18	18	18	17	18
PMV	0.02	0.04	0.04	0.04	0.03	0	-0	0		0	0.15	0.43	0.71	0.81	0.73	0.67	0.58		0.53	0.43	0.33	0.23	0.19	0.17	0.16	0.14



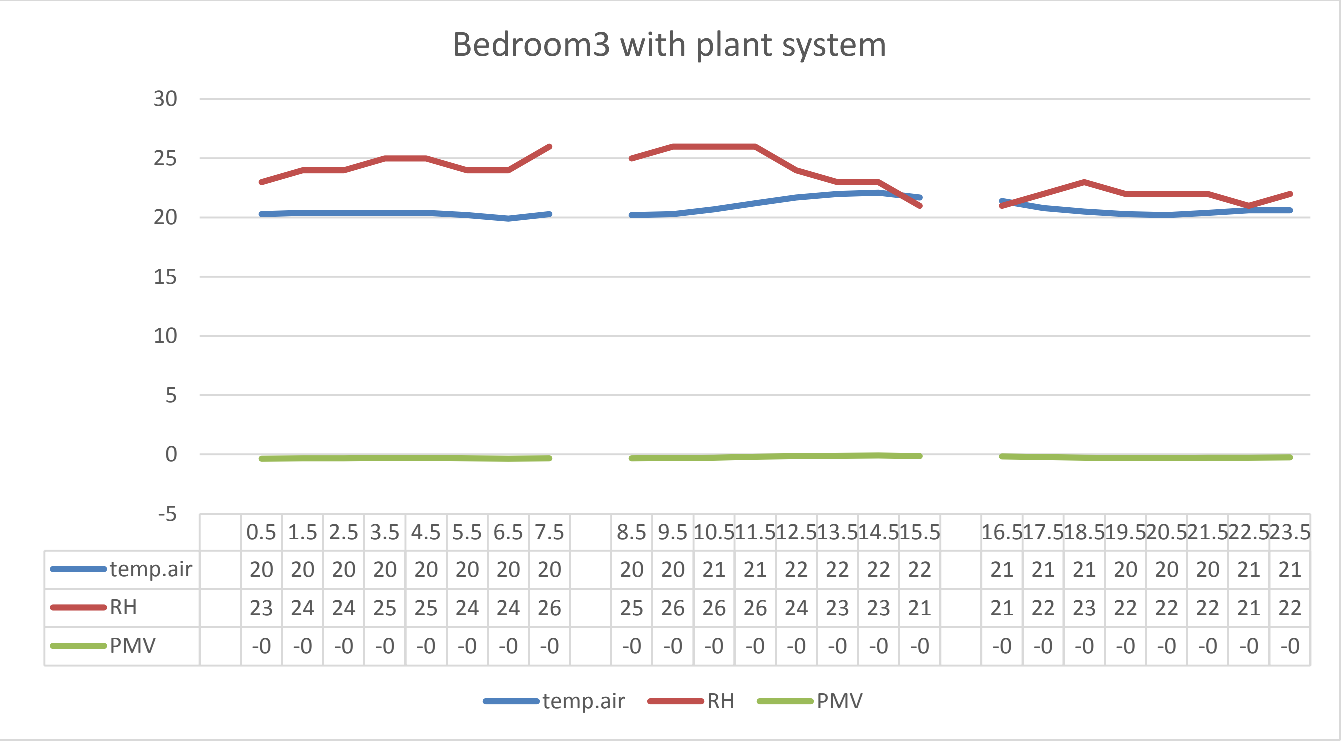
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	14	13	13	13	13	13	12	12		12	13	15	15	16	16	16	16		16	16	15	14	14	14	14	14
RH	38	38	39	39	39	39	39	40		40	41	46	51	55	57	59	60		60	60	61	57	51	47	43	41
PMV	-1	-2	-2	-2	-2	-2	-2	-2		-2	-2	-1	-1	-1	-1	-1	-1		-1	-1	-1	-1	-1	-1	-1	-1



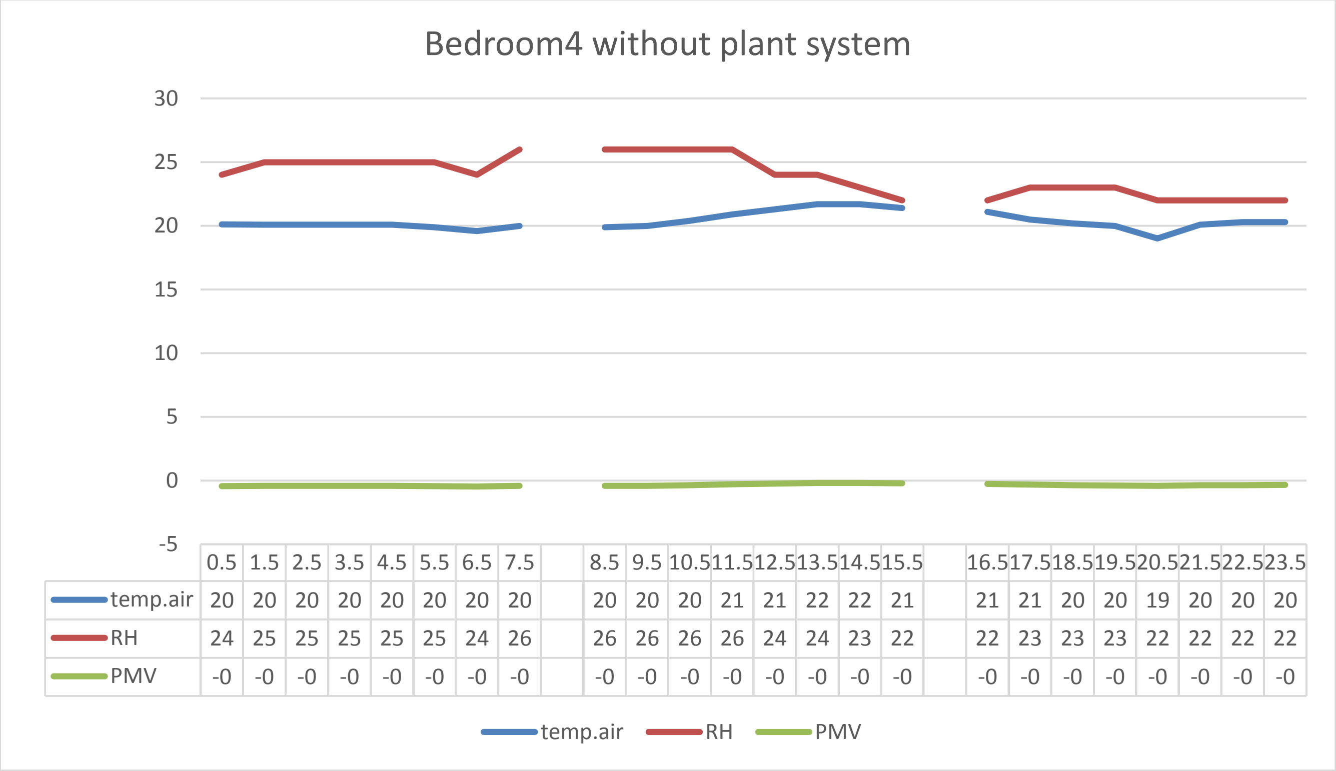
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air		20	19	19	19	19	18	19	19		19	20	21	21	21	22	22	22		22	21	20	20	20	20	20	20
RH		23	25	26	26	26	26	25	27		27	28	29	29	28	27	26	25		24	25	24	23	22	22	22	22
PMV		-1	-1	-1	-1	-1	-1	-1	-1		-1	-0	-0	-0	-0	-0	-0	-0		-0	-0	-0	-0	-0	-0	-0	-0



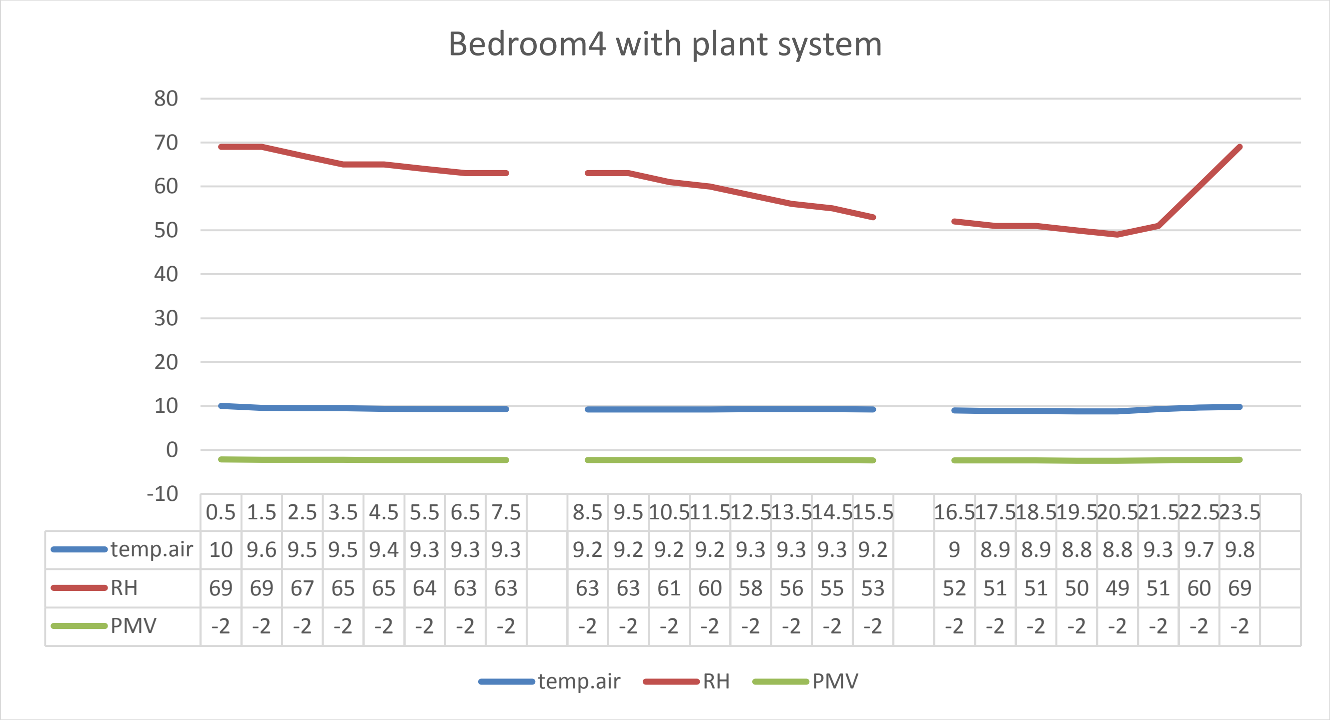
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	12	11	11	11	11	11	11	11		11	11	11	11	11	11	11	11		11	11	11	11	10	11	12	12
RH	65	73	77	80	83	85	86	88		89	88	79	71	65	60	54	53		51	49	48	47	45	45	54	62
PMV	-2	-2	-2	-2	-2	-2	-2	-2		-2	-2	-2	-2	-2	-2	-2	-2		-2	-2	-2	-2	-2	-2	-2	-2



		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air		20	20	20	20	20	20	20	20		20	20	21	21	22	22	22	22		21	21	21	20	20	20	21	21
RH		23	24	24	25	25	24	24	26		25	26	26	26	24	23	23	21		21	22	23	22	22	22	21	22
PMV		-0	-0	-0	-0	-0	-0	-0	-0		-0	-0	-0	-0	-0	-0	-0	-0		-0	-0	-0	-0	-0	-0	-0	-0

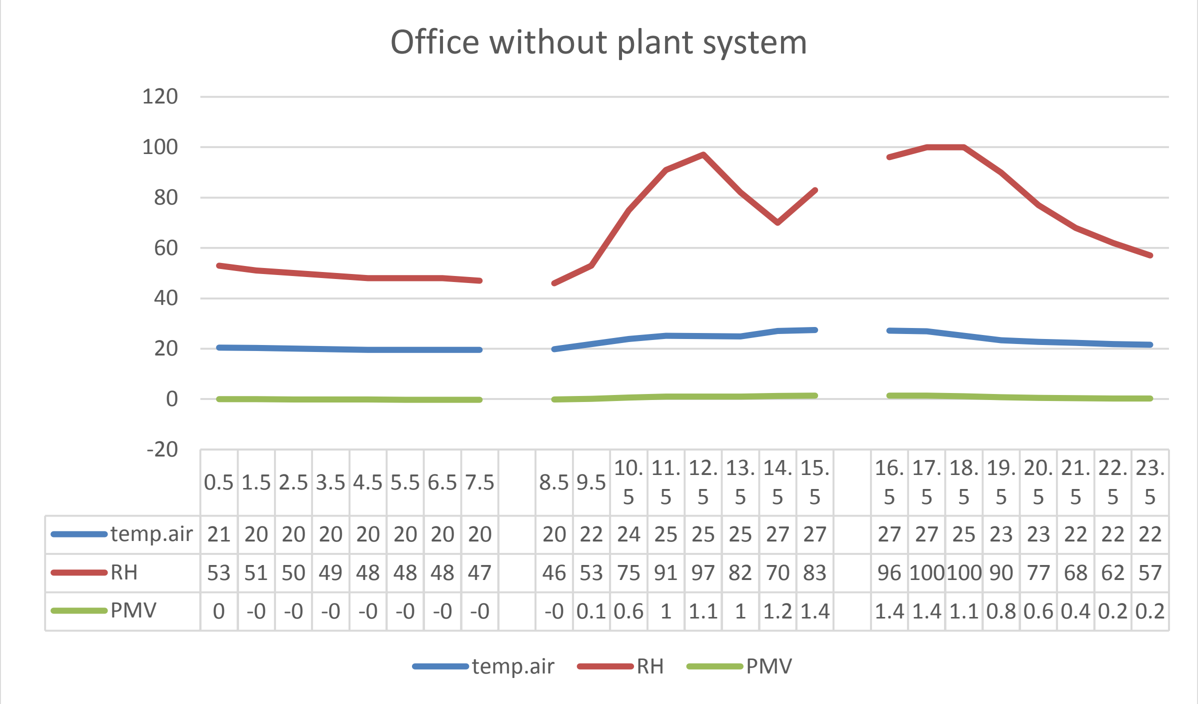


	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	20	20	20	20	20	20	20	20		20	20	20	21	21	22	22	21		21	21	20	20	19	20	20	20
RH	24	25	25	25	25	25	24	26		26	26	26	26	24	24	23	22		22	23	23	23	22	22	22	22
PMV	-0	-0	-0	-0	-0	-0	-0	-0		-0	-0	-0	-0	-0	-0	-0	-0		-0	-0	-0	-0	-0	-0	-0	-0

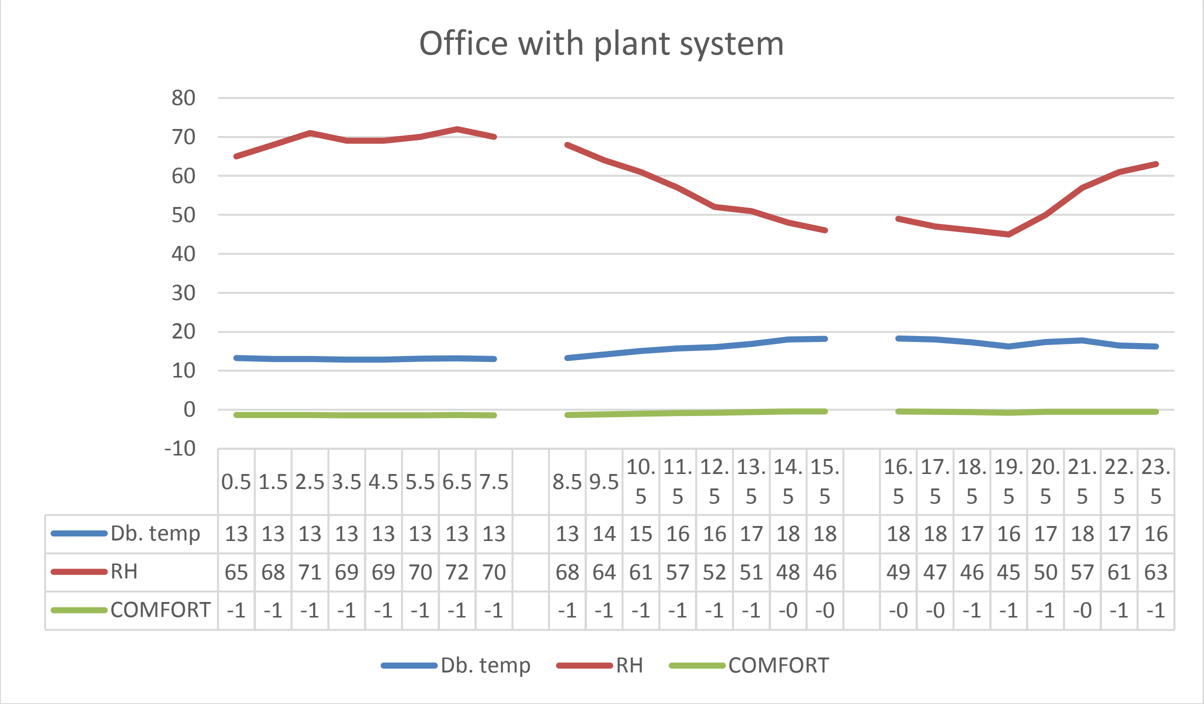


	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	
temp.air	10	9.6	9.5	9.5	9.4	9.3	9.3	9.3		9.2	9.2	9.2	9.2	9.3	9.3	9.3	9.2		9	8.9	8.9	8.8	8.8	9.3	9.7	9.8	
RH	69	69	67	65	65	64	63	63		63	63	61	60	58	56	55	53		52	51	51	50	49	51	60	69	
PMV	-2	-2	-2	-2	-2	-2	-2	-2		-2	-2	-2	-2	-2	-2	-2	-2		-2	-2	-2	-2	-2	-2	-2	-2	

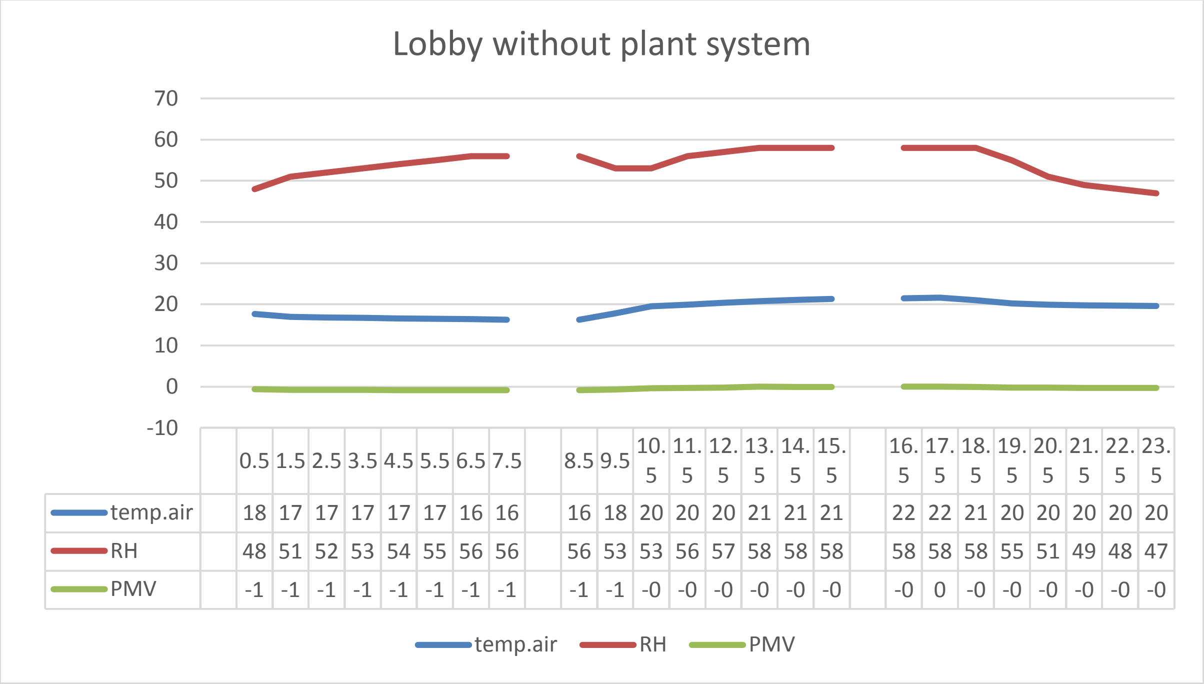
SUMMER SIMULATION-THERMAL COMFORT GRAPHS



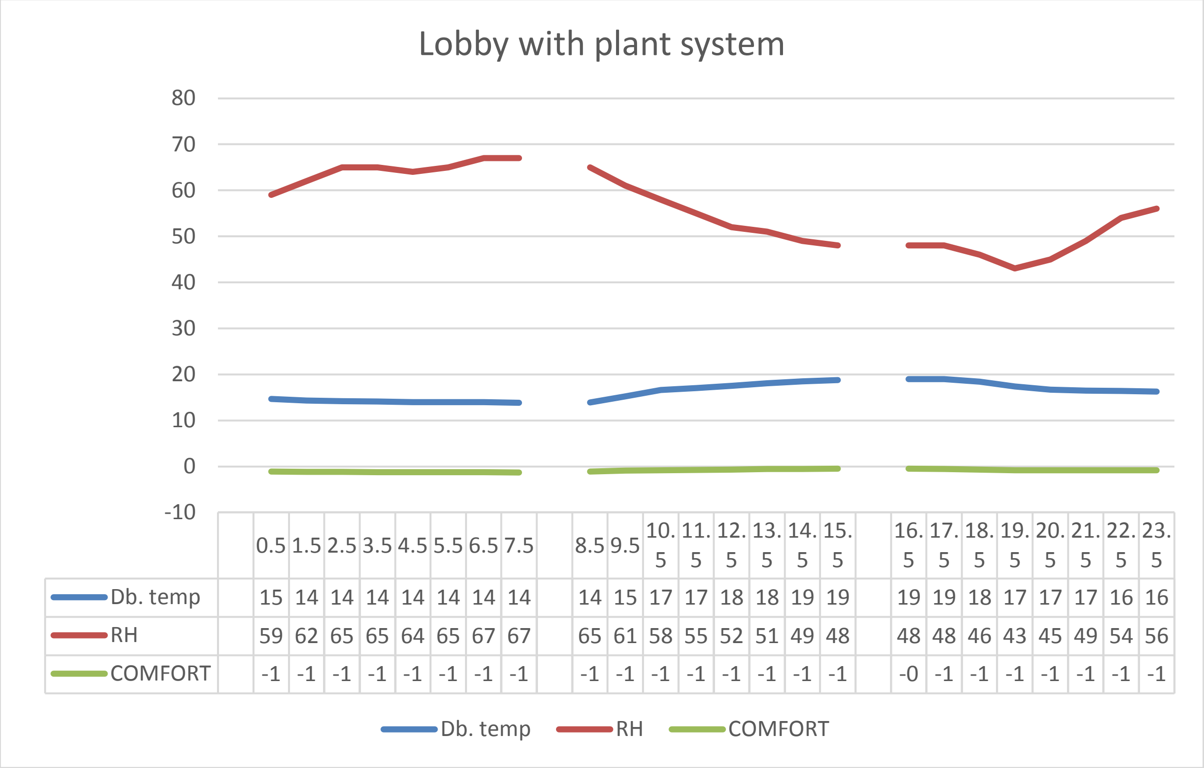
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	21	20	20	20	20	20	20	20		20	22	24	25	25	25	27	27		27	27	25	23	23	22	22	22
RH	53	51	50	49	48	48	48	47		46	53	75	91	97	82	70	83		96	100	100	90	77	68	62	57
PMV	0	-0	-0	-0	-0	-0	-0	-0		-0	0.1	0.6	1	1.1	1	1.2	1.4		1.4	1.4	1.1	0.8	0.6	0.4	0.2	0.2



	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
Db. temp	13	13	13	13	13	13	13	13		13	14	15	16	16	17	18	18		18	18	17	16	17	18	17	16
RH	65	68	71	69	69	70	72	70		68	64	61	57	52	51	48	46		49	47	46	45	50	57	61	63
COMFORT	-1	-1	-1	-1	-1	-1	-1	-1		-1	-1	-1	-1	-1	-1	-0	-0		-0	-0	-1	-1	-1	-0	-1	-1



	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
temp.air	18	17	17	17	17	17	16	16		16	18	20	20	20	21	21	21		22	22	21	20	20	20	20	20
RH	48	51	52	53	54	55	56	56		56	53	53	56	57	58	58	58		58	58	58	55	51	49	48	47
PMV	-1	-1	-1	-1	-1	-1	-1	-1		-1	-1	-0	-0	-0	-0	-0	-0		-0	0	-0	-0	-0	-0	-0	-0



	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5		8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5		16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5
Db. temp	15	14	14	14	14	14	14	14		14	15	17	17	18	18	19	19		19	19	18	17	17	17	16	16
RH	59	62	65	65	64	65	67	67		65	61	58	55	52	51	49	48		48	48	46	43	45	49	54	56
COMFORT	-1	-1	-1	-1	-1	-1	-1	-1		-1	-1	-1	-1	-1	-1	-1	-1		-0	-1	-1	-1	-1	-1	-1	-1

REFERENCES

[1] Global hotel () HOTEL DATA, Available at: http://www.globalhoteldata.com (Accessed: 10th July 2013).

[2] Susan Aryee (2011) HOTEL MAINTENANCE MANAGEMENT, : .

[3] U.S. EPA. 2008. Inventory of U.S. Greenhouse Gases Emissions and Sinks: 1990-2006, p. ES8

[4] H.E Burroughs, CIAQP, Shirley J.Hansen, PHD (2011) Managing Indoor Air Quality, 5th edn

[5] Yuanhui zhang (2004) Indoor air quality, : .[5]

[6] Imperial Machine Corporation () IMC helps UK hotel to achieve carbon neutral goal, Available at: http://www.imco.co.uk/ (Accessed: 10th July 2013).

[7] Thistle () Guoman Hotel Management (UK) Limited Achieves Carbon Trust Standard, Available at: http://www.thistle.com/ (Accessed: 10th July 2013).

[8] Paulina Bohdaniwicz, Angela Churie-Kallhauge, Ivo Martinac (2001) 'Energy-Efficiency and in Hotels Towards Sustainable Tourism', 4th International Symposium on Asia Pasific architecture, Hawai'l, (), pp.

[9] Demand Media, Inc. (2013) Energy Saving Method in UK Hotels, Available at: http://www.ehow.com/ (Accessed: 10th July 2013).

[10] Apex () APEX HOTELS CORPORATE & SOCIAL RESPONSIBILITY, Available at: http://www.apexhotels.co.uk/ (Accessed: 10th July 2013).

[11] Maritim Hotels () Environment, Available at: http://www.maritim.com/ (Accessed: 10th July 2013).

[12] GE lighting () Historic German Hotel Adlon Kempinski Checks In Deep Energy Savings with GE LED Lamps, Available at: http://pressroom.gelighting.com/ (Accessed: 10th July 2013).

[13] The Orchid () Construction, Available at: http://www.orchidhotel.com/ (Accessed: 10th July 2013).

[14] India Hospitality Review (). The air around HVAC systems in Indian Hotels, Available at: http://www.indiahospitalityreview.com (Accessed: 10th July 2013).

[15] WWF, Horwath HTL and HICAP (2010) TOWARDS THE BUSINESS CASE FOR SUSTAINABLE HOTELS IN ASIA.

[16] ECO HOTEL () ENERGY MANAGEMENT, Available athttp://www.ecotelhotels.com/ (Accessed: 10th July 2013).

[17] Go Green () Environment and Sustainability, Available at: http://www.go-green.ae/ (Accessed: 10th July 2013).

[18] Fairmont () Luxury Hotel Brand Makes Progress Toward Reducing its Greenhouse Gas Emissions by 20% as Part of WWF's Climate Savers program -, Available at: http://www.fairmont.com/ (Accessed: 10th July 2013).

[19] PR Newswire () Luxury Five-Star Hotel in Dubai Selects Telkonet's EcoSmart Energy Management Technology, Available at: http://www.prnewswire.com/ (Accessed: 10th July 2013).

[20] Alto Hotel () 1200 Buildings, Availableat: http://www.melbourne.vic.gov.au/ (Accessed: 10th July 2013).

[21] WWF, Horwath HTL and HICAP (2010) TOWARDS THE BUSINESS CASE FOR SUSTAINABLE HOTELS IN ASIA, : .

[22] Green Hotlier () Green Hotel Shower Solutions, Available at: http://www.greenhotelier.org/ (Accessed: 10th July 2013).

[23] LEED and Hotels (2009) PRACTICAL STRATEGIES in Green Building, : .

[24] EPA () Indoor Air Pollution: An Introduction for Health Professionals, Available at: http://www.epa.gov/ (Accessed: 14th July 2013).

[25] Environmental Protection Agency (1991) 'Indoor Air Facts No. 4 Sick Building Syndrome', , (), pp. .

[26] NHS () Sick building syndrome, Available at: http://www.nhs.uk/ (Accessed: 18th July 2013).

[27] Mark C. Gillott B (2000) A NOVEL MECHANICAL VENTILATION HEAT RECOVERYIHEAT PUMP SYSTEM, : The University of Nottingam.

[28] London Electricity (), Breathing life into today's homes - the benefits of whole house ventilation. London Electricity, London, UK.

[29] Centers For Disease Control And Prevention () NDOOR ENVIRONMENTAL QUALITY, Available at: http://www.cdc.gov (Accessed: 18th July 2013).

[30] Canadian Center For Occupational Health And Safety () Indoor Air Quality - Moulds and Fungi, Available at: http://www.ccohs.ca/ (Accessed: 19th July 2013).[31]

[31] Royal Borough of Kensington and Chelsea () Indoor air pollutants and health effects, Available at: http://www.rbkc.gov.uk/ (Accessed: 21th July 2013). [31]

[32] COMMUNITY ACTION TO FIGHT ASTHMA () Asthma and Indoor Air Quality in the Home: Dust Mites, Available at: http://hydra.usc.edu (Accessed: 28th July 2013).

[33] Rabbit Air () Dust Mite Allergy, Available at: http://www.rabbitair.com (Accessed: 29th July 2013).

[34] American Lung Association: Fighting for air () Dust Mites and Dust, Available at: http://www.lung.org (Accessed: 30th July 2013).[36]

[35] Canadian Center for Occupational Health And Safety () Environmental Tobacco Smoke (ETS):

[36] General Information and Health Effects Available at: http://www.ccohs.ca/ (Accessed: 1st August 2013). 37

[37] EPA () Indoor Air Pollution: An Introduction for Health Professionals, Available at: http://www.epa.gov/ (Accessed: 1st August 2013). 39

[31] Royal Borough of Kensington and Chelsea () Indoor air pollutants and health effects, Available at: http://www.rbkc.gov.uk/ (Accessed: 1st August 2013).

[38] Connecticut Department of Public Health () Healthy Homes: Indoor Air Quality, Available at: http://www.ct.gov/ (Accessed: 2nd August 2013).

[39] The Lung Association () Pollution & air quality, Available at: http://www.lung.ca/(Accessed: 2nd August 2013).

[40] EPA () An Introduction to Indoor Air Quality (IAQ) Nitrogen Dioxide (NO_2), Available at: http://www.epa.gov/ (Accessed: 2nd August 2013)

[41] Department of Health () VOCs (Volatile Organic Compounds), Available at: http://healthvermont.gov/ (Accessed:)

[42] (Minnesota Department of Health) Volatile Organic Compounds in Your Home, Available at: http://www.health.state.mn.us/ (Accessed:).

[43] Wuncheng ang, Jerald L. Schnoor, Jon Doi (1996) Volatile Organic Compounds in the Environment, 1st edn., Canada: Library of congress cataloging.

[44] Greenspec () Refurbishment / retrofit: Whole house ventilation, Available at:http://www.greenspec.co.uk (Accessed:).

[45] Steven, R. K., Parkins, L. M., Woolliscrofi, M., (1994). Passive stack ventilation systems: design and installation. Information paper IP13/94. Garston, UK, BRE.

[46] DoE, (March 1996). Domestic ventilation. General Information. Leaflet 9,

[47] Best Practice Programme. UK, HMSO.

[48] Envirovent () A guide to ventilation for self-builders, Available at: http://www.homeventilation.co.uk (Accessed:).

[49] Greenspec () Refurbishment / retrofit: Whole house ventilation, Available at: http://www.greenspec.co.uk (Accessed:).

[50] PAUL heat recovery scotland () MVHR, Available at:http://www.paulheatrecovery.co.uk/ (Accessed:).

[51] Meathvec () Mechanical Ventilation and Heat Recovery System, Available at: portal.meathvec.ie/ (Accessed:).59

[52] Robert Lowe & David Johnston (1997) 'A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY, LOW-RISE

HOUSING', Centre for the Built Environment Faculty of Health and Environment Leeds Metropolitan University Brunswick Building, (), pp.

[53] WW 2010 University of Illoinois () Relative Humidity, Available at: http://ww2010.atmos.uiuc.edu/ (Accessed:).

[54] David E. Watkins (2011) Heating Services in Buildings, 1st edn., UK: Wiley-Blackwell.

[55] DESIGNING BUILDINGS WIKI () THERMAL COMFORT IN BUILDINGS, Available at:http://www.designingbuildings.co.uk/ (Accessed:).

[56] Kostas Pavlou (2009) Thermal comfort in buildings, : .

[57] Health and Safety Executive () Thermal Comfort, Available at: http://www.hse.gov.uk(Accessed:).

[58] Arizona State University () Visualizing Thermal Comfort, Available at: http://support.caed.asu.edu/ (Accessed:).

[59] Xetex (2009) Air-to-Air Cross Flow Flat Plate Heat Exchangers, : .

[60] Ian Ball (2003) Evaluation of air to air cross flow plate heat exchanger exchanging using a new heat recovery facility, :

[61] ECONOVENT () Rotary heat exchangers, Available at: http://www.flaktwoods.co.uk/ (Accessed:)

[62] SMART HEAT () Enervent Heat Recovery Systems, Available at:http://homeenergysaving.ie/ (Accessed:)

[63] Food Tech Info () Air to Air Heat Exchanger, Available at: http://www.foodtechinfo.com/(Accessed:).

[64] Clean my Furnace () Outdoor air sources, Available at: http://cleanmyfurnace.com/(Accessed:).

[65] Heritage House () Managing and Understanding condensation in buildings, Available at: http://www.heritage-house.org/ (Accessed:).

[66] Raven housing trust () Damp and condensation, Available at:http://www.ravenht.org.uk/ (Accessed:).

[67] Ear, Nose and Throat Aliance () Dust Mite Allergens, Available at:http://www.allianceent.net/ (Accessed:).

[68] Buzzle () Facts about passive smoking, Available at: http://www.buzzle.com/ (Accessed:).

[69] Center for Environment, Commerce & Energy () EPA Proposes To Retain Carbon Monoxide Standard, Available at: http://cenvironment.blogspot.co.uk/ (Accessed:).

[70] Attack Asthma () nitrogen dioxide, Available at: http://www.noattacks.org/ (Accessed:).