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MEE4999 ENGINEERING DESIGN PROJECT

GROUP PROJECT REPORT

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	In An 24-Hours Air Conditioned Room
Supervisor	Dr. Mohammadhossein Yazdi

Declaration

We hereby declare that the project work entitled "Resolution to walls surfaces condensation & mould growth issue in an 24-hours air conditioned room" submitted to the Inti International University, is a record of an original work done by us under the guidance of Dr. Mohammadhossien Yazdi, Faculty Lecturer, Inti International University Faculty Of Science, Technology, Engineering & Mathematics, and this project work has not performed the basis for award of any Degree or diploma / associate / fellowship and similar project if any.

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Abstract

The aim of the project is to resolve the condensation and mould growth issues in a 24-hours air conditioned room. With the boundary conditions provided, a solution to optimize the design of insulation panel and installation method to prevent condensation and mould growth is proposed.

The project started by conducting case studies to identify the root of condensation and mould growth problems as well as the critical areas where the condensation most likely to occur. The fundamental knowledge of heat transfer, thermodynamics and relevant topics are applied to interpret the heat transfer operation inside and outside of the air conditioned room. A comprehensive study on the available insulation materials in the market is conducted. By comparing each material's specification, Polyurethane is the selected due to its excellent strength-to-weight ratio, insulation properties, durability and flexibility which provide effective solution for this project.

Moreover, heat transfer formulas are employed to determine the wall surface temperatures, dew point temperature and optimum insulation thickness. At the same time, the room condition is simulated using Solidworks FloEFD and Ansys Fluent software. Based on calculations, there will be condensation problem due to the outer wall temperature is lower than the dew point temperature and this is further validated with the simulated results. After analyzing the calculated results, it shows that required insulation thickness must be more than 55.52 millimeter to eliminate condensation. These parameters are then input into simulation and the simulated results show that the condensations stop which matched the calculated results. According to the insulation guideline, a safety factor of 1.5 is considered to ensure that the insulation panel is safe and will not fail when degrade over time. Hence, the actual thickness of the Polyurethane panel proposed is 83.28 millimeter.

The proposed installation method is a combination of foam spraying and foam injection method. For wall insulation, foam injection method is used to ensure seamless insulation; for roof and floor insulation, foam spraying method is selected due to these areas are hard to reach.

Acknowledgement

It is a great opportunity for us to conduct a research like "Resolution to walls surfaces condensation & mould growth issue in an 24-hours air conditioned room" in order to understand more about the effects of the condensation and mould growth problem and the possible solutions to tackle the problem. At the time conducting this research, we have gone through different books and websites which help us to acquainted with new topics. This has helped us to improve our knowledge in heat transfer, thermodynamics and relevant topics.

We acknowledge with gratitude to our project supervisor Dr. Mohammadhossien Yazdi (Faculty Lecturer, Inti International University Faculty of Science, Technology, Engineering & Mathematics) for his valuable guidance, encouragement and co-operation during the research and its presentation.

We are also thankful to our industrial partner Dr.Chong and Mr.Chong from Insafoam Insulation (Malaysia) for giving us useful feedbacks and advices throughout the project. It is an honor to have our industrial partner to attend our project presentation and be our examiners to grade our project.

We are very grateful to Engineering Faculty lecturers and staffs, Dr. How Ho Cheng, Ms. Jenny, Mr. Panir and faculty staffs who have helped us throughout the project. It was their able guidance and support, which resulted in the successful presentation of project within the specified time. Their unflinching help and encouragement was a constant source of inspiration to us.

A project owes its success from commencement to completion, to people involved with project at various stages, we avail this opportunity to convey our sincere thanks to all the individuals who have helped and assisted us in carrying and bringing out this project. Last but not least, the co-operation and help received from each team members is gratefully acknowledged.

Contents

1

List of Figures

1.0 Introduction

The aim of the project is to propose a solution to resolve the condensation and mould growth issues in a 24-hours air conditioned space such as an operation theatre in the hospital. With the consideration that the room is a superspeciality operation theatre which requires high level of cleanliness, international and national guidelines for operation theatre should be followed throughout the project. The boundary conditions inside and outside the operation theatre are given. By following the specifications, it is required to propose a solution to optimize the design of insulation panel and installation method to prevent condensation and mould growth.

By applying the fundamental knowledge of heat transfer, thermodynamics and relevant topics, the heat transfer operation inside and outside of the operation theatre is interpreted and accessed to determine the wall surface temperatures, dew point and etc. Furthermore, factors such as cost effectiveness, safety, environmental impacts and sustainability need to be taken into account during material and installation method selection for the insulation panel. The installation method should be as simple as possible and time saving for every insulation panel to be installed. The effectiveness and constructability of the proposed solution need to be evaluated and justified.

The project is divided into two stages and is to be completed in two semester's time. In the first stage of the project, the focus of the project is divided into three different parts. First, it is focused on the literature studies on published journals, articles and textbooks about the condensation and mould growth problems. This helps to ascertain the causes of the problems and identify the critical points where the condensations normally take place. By learning the root causes of the problems, the design parameters are first identified and then the functional description of the proposed concepts is discussed later.

The second part of the focus is on concepts generation based on fundamental knowledge of heat transfers, thermodynamics and existing solutions applied in the field. Theoretical calculations have been carried out to determine the inner and outer wall temperatures, as well as the dew point temperature. The heat transfer system inside and

outside of the air-conditioned space was thoroughly interpreted. The third focus area in first stage of the project is emphasized on the material selection for insulation panel and its availability as well as cost effectiveness. Several potential materials such as cellulose, coconut husk, polyolefin and silver nano-material have been considered. The properties information of these materials is obtained from internet sources and some research articles.

In the second stage of the project, the work is break down into three major parts. First, it is focused on deciding the suitable material for the insulation panel. After the first progress presentation in first stage of project, several feedbacks have been received from the industrial partners and supervisors regarding the selection of material for the insulation panel. Initially the material selected by the team was the Polyolefin, however it has been told by the industrial partners that this material is locally not suitable to be used in this project due to it is soft and will easily deformed. Based on many years of experience in building insulation service and insulation panel manufacturing, the industrial partners believe that Polyolefin might be usable in Europe countries however it is not suitable in Asia countries especially with hot and humid weather like Malaysia. Therefore, the team has worked on the feedbacks provided and gathered information to justify the limitation of Polyolefin and propose a more suitable material for the project. Through comparison and investigation, the team has finally selected Polyurethane as the insulation material in this project.

The second part of the focus is on the panel installation method for the project. Few guidelines have been considered in selecting the suitable panel installation method. Firstly, the insulation material must be able to fully adhere to the wall and ensure that there is no cavity or unfilled space especially the corners of the wall where condensations most likely occur. Secondly, the estimated service life of the insulation material and the availability of the insulation material. Thirdly, the setup before installation of panel, the ease of maintenance, and all the possible difficulties face during the installation process. By comparing several common installation methods, the team has proposed a method which is a combination of foam spraying and injection method to be employed in this project. The installation procedures are further discussed in detail in the report.

The last part of focus is determining the optimum thickness of the insulation panel. From the view point of economic effectiveness, by knowing the optimum insulation thickness, it can control the material cost and also reduces the waste of excessive material during the installation, eventually improve sustainability and environmentally friendly. The team has calculated and suggested an optimum thickness of the insulation panel using a series of formulas in the research. The detail of the calculation is shown in the following part of this report.

After the insulation material is finalized and the optimum insulation thickness is calculated, these parameters are input into simulation software FloEFD and Ansys Fluent CFD to simulate the insulation performance. The calculated results of wall surface temperatures before and after insulation are compared and validated with the simulated results. The results obtained from manual calculations matched the simulated results, hence proved that with the calculated optimum insulation thickness and Polyurethane as the insulation material, the condensation and mould growth issue can be eliminated.

Before all the analysis works begin, the planning and management of the project as well as the responsibility of each group member were clearly defined. A comprehensive Gantt chart was generated to set an execution and completion time for each task. This acts as a guideline to ensure that all tasks will follow or ahead of the schedule.

2.0 Problem Statement

Condensation and mould growth issues have become major concerns and expensive dilemma for hospitals. They are not only damage the structure of the facilities but also threaten patients' life. These phenomenons often take place in humid areas such as 24-hours air-conditioned operation theatres. Therefore, proper insulation is essential to control the condensation and mould growth to provide a safety environment. An appropriate insulation material and optimum insulation thickness are to be determined to solve the problem. At the same time, the proposed insulation panel should be cost effective, ease of installation and adhere to health and safety regulations.

3.0 Objectives

- To simulate the internal and external heat transfer of the air conditioned space using FloEFD and Ansys Fluent CFD software.
- To optimize the design of insulation panel to the walls of 24-hours air conditioned space with suitable insulation material and optimum insulation thickness.
- To introduce cost effective, safe, and time saving solutions to resolve external wall surfaces condensation and mould growth problems.
- To introduce a simple, effective and practical insulation panel installation method for condensation and mould growth control.

4.0 Theory

4.1 Mould Growth

Moulds are microscopic organisms that are present virtually everywhere in surrounding environment. Moulds will break down dead organic materials and recycle nutrient back into the environment. Moulds are commonly found on wall or ceiling as shown in figures 1(a) and 1 (b) where there is water damage, high humidity, or dampness especially inside or outside of air conditioned room which has high moisture content and cooler surface where condensation take place. Mould growth is encouraged by warm and humid conditions and all that is necessary for mould growth to start is moisture. The microscopic cells can spread easily through air and harmful to human health when human inhale to their body (Joseph, L., 2002). Therefore, effective solution is essential to stop mould growth in our working and living spaces.

Mould growth relies heavily on four factors which are the spores, temperature, moisture and food source. Mould spores are always present in both indoor and outdoor air and the can flourish in any ambient temperature from 4°C to 38°C. The presence of mold spores cannot be avoided; however it is possible to take steps to control the moisture the mold needs. Adding mould resistance construction materials to the critical

4

places where the mould will grow to prevent condensation is a part of the strategy. By adding resistance, it will retain as little moisture as possible.

In humid and warm countries such as Malaysia, moulds normally grow on the exterior wall surfaces of the air-conditioned space. Typically, the temperature of the exterior wall surface will be cooler than the outer ambient air temperature and therefore condensations normally happen on the outer wall. In order to limit the temperature difference between the exterior wall and the ambient air, it can be resolved by installing insultaion to the inner wall to restrict the heat transfer from inside to outside as well as reduce the potential for condensation on cold surfaces (Joseph, L., 2002).
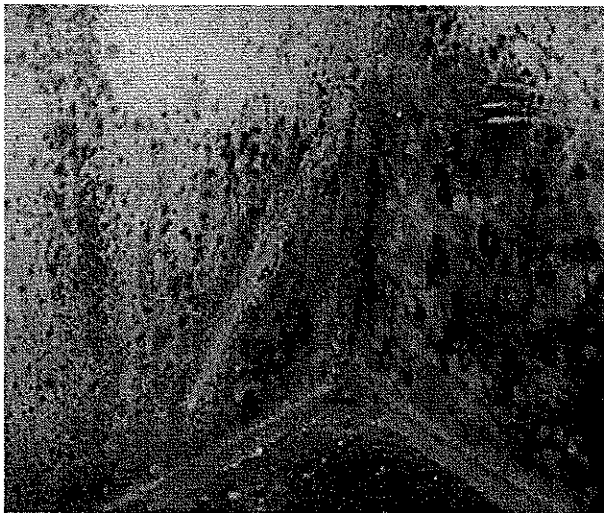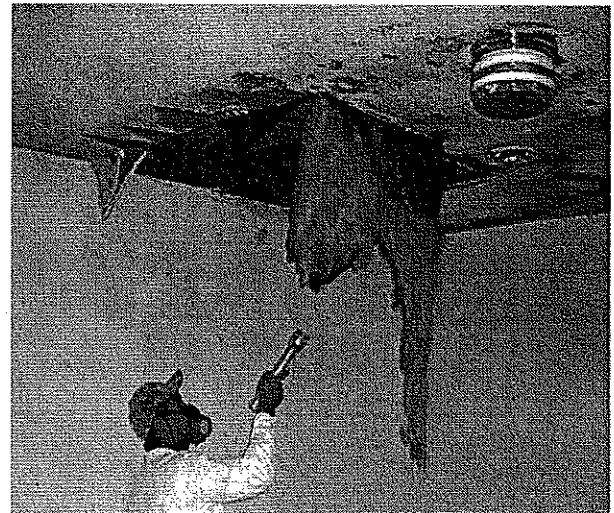
1(a)   1(b)

Figure 1(a) & (b): Mould growth problems at the corners of the wall and also at the ceiling (Eastern Health Authority, n.d.) & (Toxic Black Mould, n.d.).

4.2 Heat Transfer

Heat is the form of energy that can be transferred from one system to another as a result of temperature difference. A thermodynamic analysis is concerned with the amount of heat transfer as a system undergoes a process from one equilibrium state to another. The science that deals with the determination of the rates of such energy transfers is the

heat transfer. The transfer of energy as heat is always from the higher-temperature medium to the lower-temperature one, and heat transfer stops when the two mediums reach the same temperature (Yunus, A.C. & Afshin, J. &Ghajar., 2011).

Heat can be transferred in three different modes which are conduction, convection and radiation as shown in figure 2. All modes of heat transfer require the existence of a temperature difference, and all modes are from the high temperature medium to a lower temperature one.
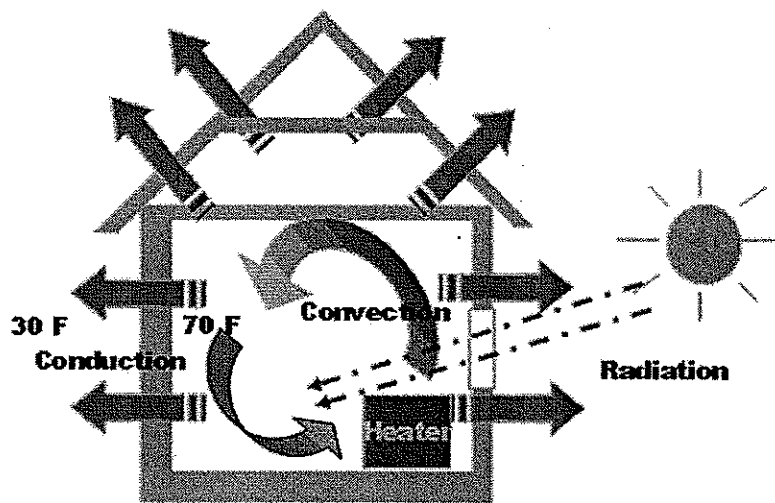
Figure 2: Three modes of heat transfer which are conduction, convection and radiation (Pisupati, S., 2014).

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction commonly takes place in solids, liquids or gases. The rate of heat conduction through a medium depends on the geometry of the medium, thickness, the material of the medium and the temperature difference across the medium.

In this project, the heat conduction normally takes place through the four walls in the room with a thickness of   and area A, as shown in figure 3. The temperature difference across the wall is   .
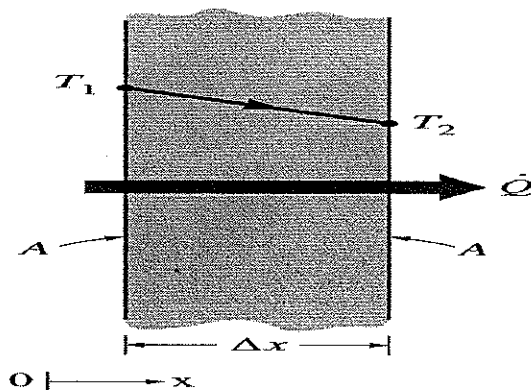
Figure 3: Heat conduction through a wall with a thickness (Yunus,A.C. & Afshin,J. &Ghajar., 2011).

The rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer (Yunus,A.C. & Afshin,J. &Ghajar., 2011).

$$\text{Rate of heat conduction} \quad \propto \frac{(Area)(Temperature\ difference)}{Thickness}$$

or

$$\dot{Q}_{Conduction} = kA\frac{T_1 - T_2}{\Delta x} = -kA\frac{\Delta T}{\Delta x} \quad (W) \tag{1}$$

where the constant of proportionality k is the thermal conductivity of the material, which is a measure of the ability of a material to conduct heat. In this project, the wall material will be concrete and hence the thermal conductivity used in the calculation will be the k value for concrete.

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfers. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction (Yunus,A.C. & Afshin,J. &Ghajar., 2011).

7

There are two types of convection which are the forced convection and natural or free convection. Forced convection is when the fluid or air is forced to flow over the surface by external means such as a fan, pump, or the wind. In this project, the type of convection considered is only forced convection due to the air inside the air conditioned space is pumped by air conditioning system and the air contacts with the outer wall surface is blow by nature wind.

In contrast, convection is called natural or free convection if the fluid or air is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid or air. However, in this project natural convection will not be considered due to the absence of buoyancy forces (Yunus,A.C. & Afshin,J. &Ghajar., 2011).

The rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling as

$$\dot{Q}_{convection} = hA_s(T_s - T_\infty) \qquad (W) \qquad (2)$$

where,

h is the convection heat transfer coefficient in $W/m^2.°C$,

A_s is the surface area through which convection heat transfer takes place,

T_s is the surface temperature,

T_∞ is the temperature of the fluid or air sufficiently far from the surface.

Radiation is the energy emitted by matter in the form of electromagnetic waves as a result of the changes in electron configurations of the atoms or molecules. When a surface of emissivity and surface area A_S at an absolute temperature T_S is completely enclosed by a much larger (or black) surface at absolute temperature T_{surr} separated by a gas (such as air) that does not intervene with radiation, the net rate of radiation heat transfer between these two surfaces is given by

$$\dot{Q}_{rad} = \varepsilon\sigma A_S(T_S^4 - T_{Surr}^4) \qquad (W) \qquad (3)$$

8

where,

$= 5.67$ W/m^2.K^4 is the Stefan-Boltzmann constant

is the emissivity of the surface.

4.3 Condensation

Condensation is the formation of liquid droplets from water vapor. Condensation commonly occurs when a vapor is cooled and/or compressed to its saturation limit when the molecular density in the gas phase reaches its maximal threshold. Condensation in the atmosphere usually occurs as a parcel of rising air expands and cools to the point where some of the water vapor molecules clump together faster than they are torn apart from their thermal energy. In general, condensation is defined as the change in the state of water vapor to liquid water when in contact with any surface (AKCmed, n.d.).
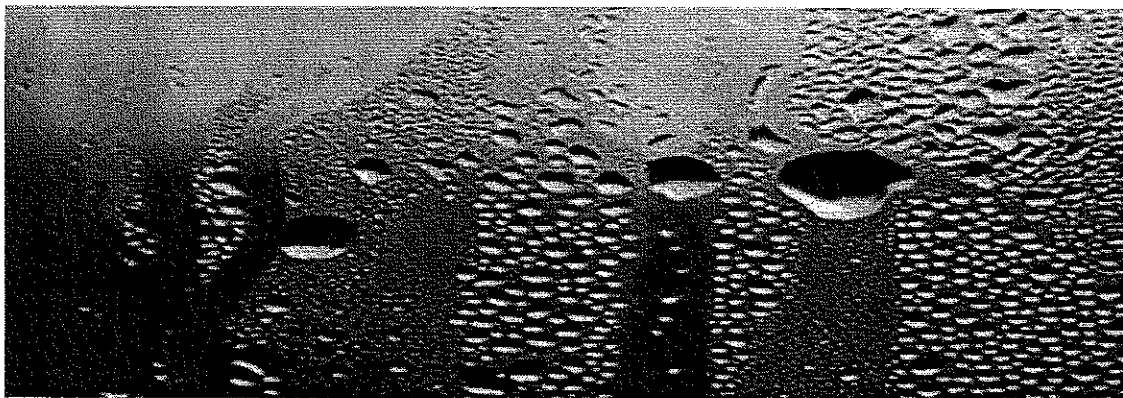
Figure 4: Water droplets form on the cold surface due to condensation (Dalgan Windows, n.d.).

A very important part of this process is the release of the latent heat of condensation. The way in which condensation occurs is on hard surfaces, for example during the formation of dew. Water condensing on the cold wall surface, or on the inside of windows during winter, is the result of those glass surfaces' temperature cooling below the dew point of the air which is in contact with them.

However, condensation in building construction or extreme places which require high cleanliness such as hospital operation theatre or food industry is an unwanted phenomenon because it may cause dampness, mould health issues, corrosion and energy loss due to increased heat transfer. To resolve these problems the air ventilation system in the building is crucial to move the air throughout the building. Besides improving the air ventilation system, insulation panels can be considered to limit the heat transfer and prevent condensation to take place (Joseph,L., 2002).

In country such as Malaysia which has hot and humid climates, humid weather and cooling periods present the opposite challenge. Building assemblies need to be protected from getting wet from the exterior, and they must be allowed to dry towards the interior. Accordingly, air barriers and vapor barriers are installed on the exterior of building assemblies. Additionally, building assemblies must be allowed to dry towards the interior by using permeable interior wall finishes and installing cavity insulations without vapor barriers (unbacked fiberglass batts or blown cellulose or rock wool). Avoid any impermeable interior wall coverings such as vinyl wallpaper. Furthermore, conditioned spaces are maintained at a slight positive air pressure with conditioned (dehumidified) air to limit the infiltration of humid outdoor air (Joseph,L., 2002).

4.4 Dew Point Temperature

The dew point temperature is the temperature at which air is saturated with water vapor, which is the gaseous state of water. When air has reached the dew-point temperature at a particular pressure, the water vapor in the air is in equilibrium with liquid water, meaning water vapor is condensing at the same rate at which liquid water is evaporating. The dew point is always lower than or equal to the air temperature (Fredlund, D.G. & Rahardjo,H. & Fredlund, M.D., 2012).

Below the dew point, liquid water will begin to condense on solid surfaces or around solid particles in the atmosphere. Dew point is closely linked to relative humidity, which is the ratio of the pressure of water vapor in a parcel of air relative to the saturation

pressure of water vapor in that same parcel of air at a specific temperature. Relative humidity (RH) is expressed as a percentage.

The relative humidity is 100 percent when the dew point and the temperature are the same. If the temperature drops any further, condensation will result, and liquid water will begin to form. Compared to relative humidity, dew point is frequently cited as a more accurate way of measuring the humidity and comfort of the air, since it is an absolute measurement unlike relative humidity.

Dew point temperature can be determined graphically using a psychometric chart or mathematically using dew point formula. The Bosen (1958) equation was developed for the approximation of dew-point temperature when relative humidity and dry bulb temperature are known (Fredlund, D.G. & Rahardjo,H. & Fredlund, M.D., 2012). The Bosen's equation for the calculation of dew point is given by,

$$Td = (r/100)^{1/8} (112+0.9T) + 0.1T - 112 \tag{4}$$

where,

Td = dew point temperature in °Kelvin (K)

r = relative humidity, and

T = the air temperature in °K

Note that: 273.15°K = 0°C

4.5 Operation Theatre

Operation Theatre is a space where the amount of particles such as dust or bacteria of a certain size per cubic meter are controlled. Air temperature, humidity, pressure and noise levels should be also regulated. These types of rooms are used in pharmacology and in medicine to prevent infection in the patient's body, in microelectronics in the production of electronic equipment, etc. (Kovalenko, 2013)
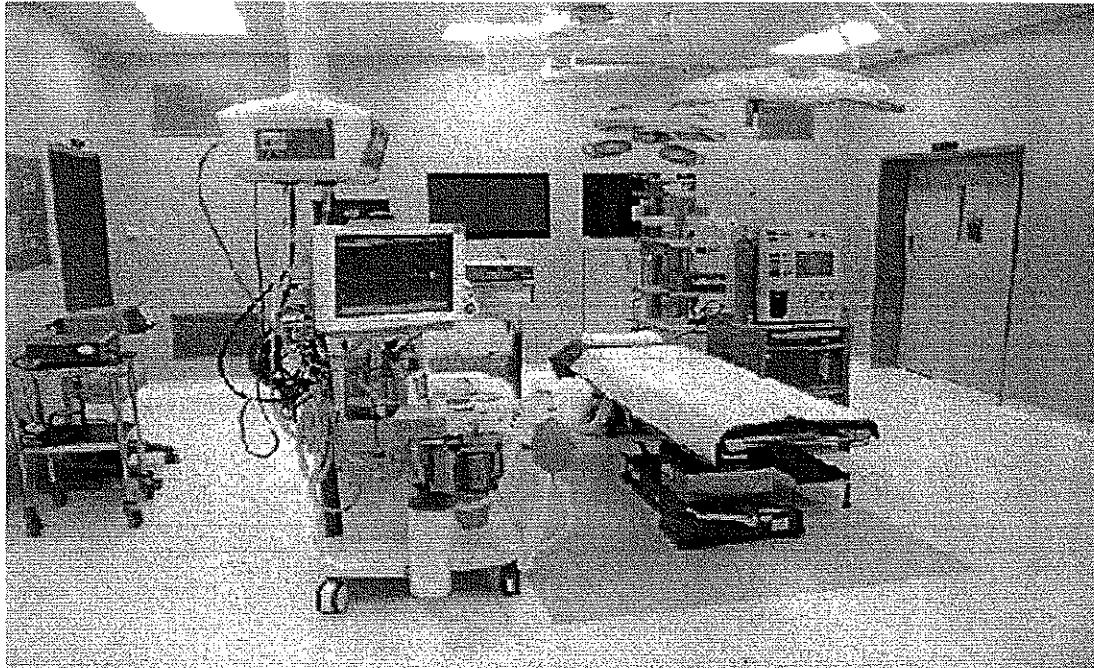
Figure 5: Standard operation theatre in hospital (AKCmed, n.d).

The cleanliness of operation theatre in hospitals is most significant, because they affect people's lives. There is a risk of nosocomial infections (hospital-acquired infection) and postoperative infectious complications. The health and work of doctors also depend on the purity of the air. That is why it is very important to be careful in the design of ventilation in hospitals (NABH, 2010).

To provide sufficient air quality in the operating room there must be properly working ventilation. Air Handling Unit (AHU) for operating rooms is not connected with the ventilation system hospital. Air passes through several stages of purification filters with various purity types before entering into the operating room. Two filters are installed in the AHU and the final cleaning filter is installed into a laminar flow ceiling (NABH, 2010).
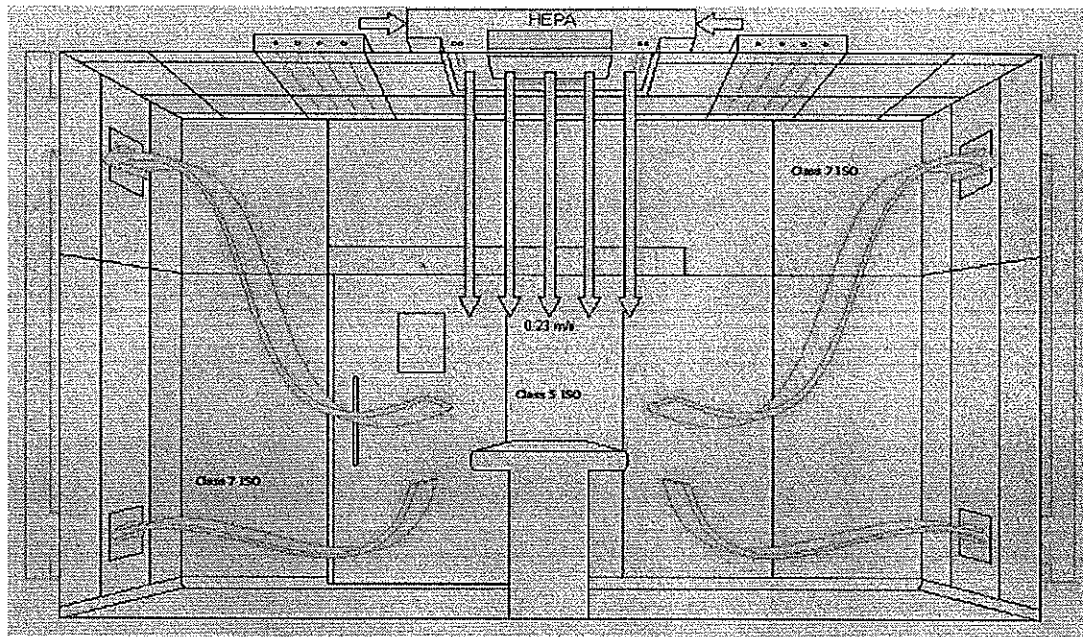
Figure 6: Air conditioning / HVAC system in the operation theatre (AKCmed, n.d).

The hospital operation theatres are commonly 24 hours air-conditioned, and therefore there will have a high chance for condensation at the outer part of the operation theatres. The differential temperature between rooms has induced condensation and it can be a possible threat to the patients. Mould mitigation solution should be conducted immediately to prevent spread of mould. As for long term strategy, insulation panel is one of the solutions which can solve the mould growth problem effectively by limiting the heat transfer between the rooms.

There are several revised guidelines for air-conditioning system for operation theatres. The minimum air changes should be 30 based on international guidelines and the fresh air component of the air change is required to be minimum 5 air changes out of total minimum 30 air changes. The vertical down flow air coming out of the diffusers should be able to carry particle load away from the operating table. The airflow needs to be unidirectional and downwards on the OT table. The air velocity recommended as per the international and national guidelines is 90-120 FPM or 0.46 m/s to 0.61 m/s at the diffuser level (NABH, 2010). Moreover, the temperature should be maintained at 21 +/-

13

3 °C inside the OT all the time with corresponding relative humidity between 40 to 60 % through the idea RH is considered to be 55%. Furthermore, there is a requirement to maintain positive pressure differential between OT and adjoining areas to prevent outside air to entry into OT. The minimum positive pressure recommended is 15 Pascal as per ISO 14644 Clean Room Standard (NABH, 2010).

4.6 Corner Surface Temperatures

The relative humidity at the wall surfaces influences the risk of condensation and mould growth at the interior surfaces of the building significantly. The temperature of the indoor corner against the façade is often lower than the mean wall surface temperature during heating season (Schijndel, A.W.M.V., 2007). These corner surfaces could be risk areas for mould growth as there are lower temperatures which result in higher relative humidity as shown in figure 1.
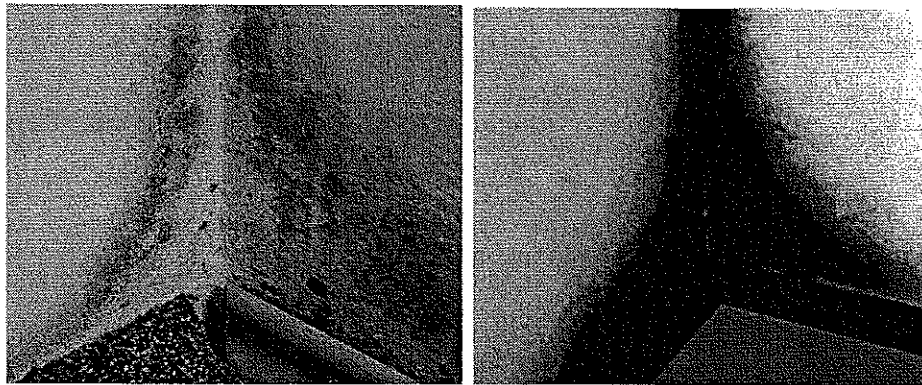
Figure 7: Mould growth at the wall corner surfaces (Schijndel, A.W.M.V., 2007).

In some researches state that a rough criterion to prevent mould growth is that the monthly mean relative humidity at the surfaces must be lower than 80% (Schijndel, A.W.M.V., 2007). When this condition is met, the risk of mould growth is acceptable, but still not excluded. Because it is difficult to determine whether conditions are met, hence it is where the necessity of insulation panels comes into hand.

4.7 Optimum Thickness

Heat transfer coefficients of external and internal wall have significant impact on heating and cooling demand. Changing thickness of insulation layers is direct way to improve the heat transfer coefficient. However, this strategy always leads to a higher investment. There should be an optimum thickness, which could make the balance between increased investment of insulation layer and the decreased cost for heating and cooling (Zhu, P. & Huckemann, V. & Norbert, F.M., 2011).

Effective thermal protection in residential sector plays an important role towards the reduction of energy consumption for space heating. Insulation reduces fuel consumption, undesirable emissions and increases thermal comfort by minimizing heat losses from building.

With the consideration of climatic condition, heating and cooling parameters and insulation material, the optimum thickness of thermal insulation layer for internal wall can be calculated.

5.0 Literature Review

In most of the previous work, studies had been made upon finding a suitable and viable solution to minimize or to prevent heat transfer through wall and also to counter the issue of indoor condensation that will in the end give rise to mould growth issues. Be it in tropical region or cold region, mould growth in indoor area especially the wall is inevitable. Researchers had come up with experiments and studies to investigate the usage of heat insulation panel to prevent heat conduction through wall that could cause condensation.

The impact of having condensation in the indoor that could lead to mould growth is serious towards the occupants. A paper was done by Stephen D Platt in 1989 (Platt et al., 1989) regarding the effect of condensation and mould growth towards the housing condition as well as health. Damp and mouldy living condition can lead to serious illness like nausea, blocked nose, breathlessness, backache, fainting and bad nerves. Children are more susceptible by mould as they usually develop respiratory complications, headaches and fevers while living in damp and mouldy condition.

In 2011, Panyu Zhu (Zhu, Huckemann and Fisch, 2011) from the University of Braunschweig, Germany has studied the effect of the optimum thickness of wall insulation in different climate zones in China towards energy saving. The study mainly focuses on external wall insulation and with the aid of calculation, it is found that with better material and thicker insulation, the energy saving can be increased. However, the research was done only on external wall application and it does not show how internal wall insulation could affect the energy saving.

Fayez Aldawi (Aldawi et al., 2013) from the School of Aerospace, mechanical and Manufacturing Engineering, RMIT University, Melbourne has studied the effect of climates and building materials on house wall thermal performance in Australia. The study has found out that with the current new wall system available in Australia, the system can provide high energy efficiency and also the reduction in greenhouse gas emission. The study was made with single panel insulation with 2 different insulation material, polyurethane and polystyrene, and also another experiment where the insulation thickness was doubled. It was found that the single layer insulation of polyurethane has 40% better efficiency compared to polystyrene in single layer. By doubling the thickness of both materials, the energy efficiency was further improved by 5% to 10%. This study is promising in proving the positive effect of new wall insulation system, but it doesn't provide information about the vapor retardant properties of both of the materials.

Safety of the usage of insulation material is imperative. An experimental study was made to determine the combustion characteristics of polyurethane insulation panel with aluminium composite under different heat fluxes. This study was conducted by Jun Xu (Xu and Fang, 2013) from the Engineering Research Center of Buildings Energy-Efficient Control and Evaluation, Ministry of Education, Hefei. Characteristics including ignition time, heat release rate, mass loss rate, concentration of gas component and other parameters are analyzed under different heat fluxes. Using classical formula, they were able to predict the pyrolysis of the material, but the critical heat flux was unable to be determined and also improvement on the flame and toxic smoke retardant of the material was not mentioned. Another research on the fire safety property of insulation material was made in Beijing by Jing Jin (Jin et al., 2014). The research was done to determine the

flame retardant properties of mixture rigid polyurethane foam and expandable graphite composites. It was found that the material would produce a char layer that can prevent heat transport, which can delay the diffusion of volatile combustible fragments to flame zone.

All the above mentioned researches were done on only the insulation material itself with no additional different material. Haeyong Jung (Jung, Yeo and Song, 2014) studied the Aluminium-foil-bonded enveloping and double enveloping for the application of the vacuum insulation panels (VIP). These 2 different enveloping methods were analyzed based on their ability to enhance the service lifetime and to reduce the degree of edge conduction. It was found that the double enveloping method has a better service lifetime compared to case of single enveloping. Double enveloping also has a decrease in overall thermal conductivity at the edge. Besides, with both of these enveloping methods, the gas permeation rate was found to be virtually zero, which could also act as moisture retardant.

Evy Vereecken (Vereecken and Roels, 2014) made a study to compare the hybrid performance of 2 different insulation systems using a hot box- cold box experiment. The study was made on application of interior insulation on a small test masonry wall and the moisture content in the wall was measured by weighing the test wall and investigated using X-ray projection method. Capillary active and non-capillary active airtight insulation was investigated and it was found that capillary active system has higher moisture content stored inside the wall. This study proves that insulation material needs not only to provide thermal insulation but also vapor retardant property to prevent moisture permeation.

To produce a feasible as well as sustainable insulation panel, cost is an inevitable measure regardless of how effective the material can be. A study on the cost benefit and potential emission reduction evaluation of applying thermal wall insulation for the buildings in Malaysia was made by M. Shekarchian (Shekarchian et al., 2012) from the University of Malaya. The focus of the study was to determine the available insulation materials in Malaysia that is economically feasible while at the same time were able to provide energy efficiency. Findings from the research shows that with 2.2cm of

fiberglass-urethane gives the best cost saving of around 1.86$/m^2 and it is able to reduce annual CO_2 emission level by 16.4kg/m^2. This research gives an overview on how different materials with different properties as well as thickness can affect the overall cost and also long term cost like the electrical tariff. The only thing lack in this research is the cost that relates to the method of installation of the panel as well as lifetime maintenance cost.

5.1 Potential Insulation Materials

5.1.1 Polyolefin

The superior performance of polyolefin in thermal insulation and zero vapour permeability are the reasons for the polyolefin being widely used in the industry. Sekisui Foam Australia – one of the leading companies in insulation solution field which nominated as the top ten green energy building company has invented a thermal and vapour insulation material named Thermobreak which uses polyolefin foam. Polyolefin has provided the Thermobreak flexibility which made from physically crosslinked, closed cell, and thermally fused to pure reinforced aluminum foil. Thermobreak provides superior energy saving performance and it lower thermal conductivity than other flexible closed cell thermal insulation materials and has near zero vapour permeability (Sekisui, 2014).
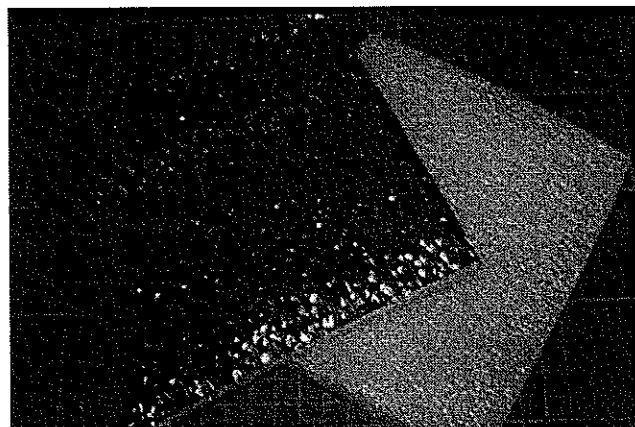

Figure 8: Polyolefins foam (BETAFOAM, 2015)

Polyolefins are the largest group of thermoplastics, often referred to as commodity thermoplastics. Polyolefin has a closed-cell structure and offer great water, chemical, and abuse resistance. The closed-cell structure of polyolefin insulation also provides its thermal properties (k value). Polyolefin surfaces are not effectively joined together by solvent welding because they have excellent chemical resistance and are unaffected by common solvents. They are extremely inert chemically but exhibit decreased strength at lower and higher temperatures. One of the main problems of Polyolefins is that without special treatment it is not readily biodegradable, and thus accumulates. Moreover, Polyolefin are high thermal expansion, subject to stress cracking, difficult to bond, flammable, poor temperature capability. One of the limitations of Polyolefin is their tendency to be exposed, in the presence of water, to the formation of bush-shaped defects, so called water trees, which can lead to lower breakdown strength and failure to insulate. This tendency is strongly affected by the presence of inhomogeneities, microcavities, and impurities in the material (Smedberg, A. & Bostroem, J.O & Eklind, H., 2008).

The heat resistance of the irradiated polyolefin insulation is limited primarily by the degradation of the strength and flexibility properties with heat aging at elevated temperatures. The most severe limitation has been found to be the reduction in flexibility and strength during heat aging in an oxygen environment while under substantial stress (Paul, M.C. & Richard, W.M. & Howard, R., 1959).

Thermoplastic materials are very susceptible to temperature spikes even for a short period above their service limit. If the temperature is reduced, the material will not return to its previous shape because the cell walls collapse and hence will no longer perform as an insulator. Figure 9 shows the effects of exceeding the service temperature limits for both types of insulation.
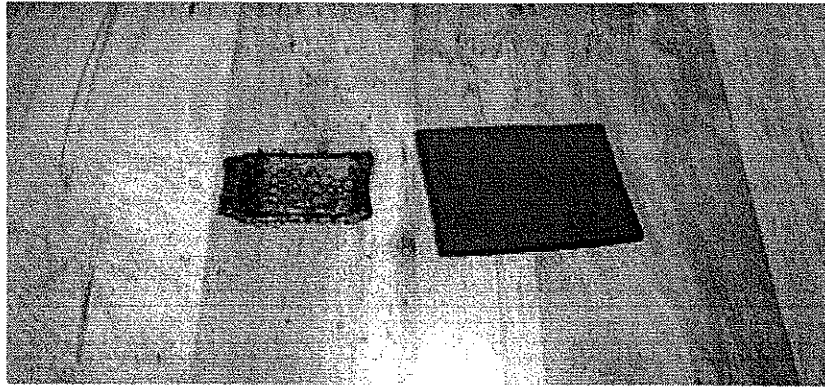
Figure 9: The effects of exceeding the service temperature limits (David, J.L., 2003).

The sample on the left is a polyethylene-based material and the sample on the right is an elastomeric material. Each sample was exposed to a temperature corresponding with the upper service temperature limit for a period of 6-hours. Both samples were originally of the same size and thickness (David, J.L., 2003).

Polyethylene insulation has a lower temperature limit than elastomeric insulation. For service temperature limits see Physical Properties Comparison.
Because CCF is generally more rigid and dense than fiberglass insulation, it does not absorb sound as well as fiberglass (David, J.L., 2003).

5.1.2 Polyurethane

Polyurethanes are one of the most versatile plastic materials. Polyurethanes are found in all facets of building construction from product manufacturing to solving critical application needs on the job. They are used as insulation, adhesives, sealants and binders in a variety of construction products and in numerous other uses. The desire and need for more energy efficient buildings has encouraged the use of more polyurethane products. Today's homes demand high-performance materials that are strong, yet lightweight; perform well, yet are easily installed; and are durable, but also versatile (American Chemistry Council, Inc., 2005).
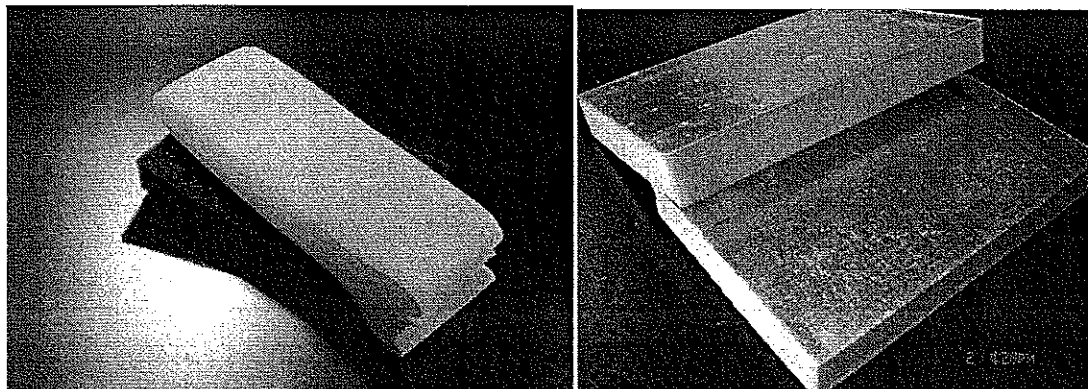
Figure 10: Polyurethane foam (American Chemistry Council, Inc., 2005).

Polyurethane helps conserve natural resources and helps preserve the environment by reducing energy usage. With its excellent strength-to-weight ratio, insulation properties, durability and versatility, polyurethane is frequently used in building and construction applications. Both the affordability of these versatile materials and the comfort they provide homeowners have made polyurethane components part of homes everywhere (American Chemistry Council, Inc., 2005).

The nature of the chemistry allows polyurethanes to be adapted to solve challenging problems, to be molded into unusual shapes and to enhance industrial and consumer products. Polyurethanes are formed by reacting a polyol (an alcohol with more than two reactive hydroxyl groups per molecule) with a diisocyanate or a polymeric isocyanate in the presence of suitable catalysts and additives. Because a variety of diisocyanates and a wide range of polyols can be used to produce polyurethane, a broad spectrum of materials can be produced to meet the needs of specific applications. There are several types of Polyurethane such as Flexible Polyurethane Foam, Rigid Polyurethane Foam, Thermoplastic Polyurethane and more. In this project, Rigid Polyurethane has been employed as the insulation method to solve condensation problem in the air conditioned room. Rigid polyurethane and polyisocyanurate (polyiso) foams create one of the world's most popular, energy-efficient and versatile insulations. These foams are effective insulation materials that can be used in roof and wall insulation, insulated windows, doors and air barrier sealants. The good thermal insulating properties