INVESTIGATION INTO THE PERFORMANCE OF A DESICCANT COOLING SYSTEM COMBINED WITH CHILLED CEILING

(PENYIASATAN TERHADAP PRESTASI SISTEM PENDINGINAN YANG BERGABUNGAN PENGERING UDARA DAN SILING TERSEJUK)

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MARCH 2005

This dissertation is submitted to

University Sains Malaysia

As partial fulfillment of the requirement for Bachelor Degree with Honors in

MECHANICAL ENGINEERING

School of Mechanical Engineering

Campus of Engineering

Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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ACKNOWLEDGEMENT

At the beginning, I would like to thank the school in giving me the opportunity to undertake and complete the project. I also take this opportunity to thank my supervisor, Associate Professor Ahmadul Ameen for his help towards completion of this project. His professional advice and guidance allowed me to learn a lot of about this new concept of air conditioning system. It may be a valuable experience for me to succeed in future.

Secondly, I would also like to thank Mr. Mahmud K, a graduate student of the school for helping me during the experiments and providing me with a lot of useful background knowledge throughout the period. His willingness to help me has been a very stimulating experience. I am also very appreciative of all staff of the School of Mechanical Engineering who has given help to complete my final year project.

Lastly, I wish to thank my friends from the Universiti Sains Malaysia for provide me and helping me to find a lot of important information and source. Without their helping hands, I might not be able to complete this thesis successfully. All experiences will be my precious memory in future.

Thanks.

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Δh	Change of enthalpy (kJ/kg)
υ	specific volume (m^3/kg)
$\dot{V}$	Volume flow rate (m^3/s)
$\dot{m}$	Mass flow rate (kg/s)
q	Heat load per area (W/m^2)
r	Room
A	Area (m^2)
H	Height (m)
L	Length (m)
P	Power (kW)
Q	Heat load (W)
T	Temperature (˚C)
W	Width (m)
CC	Cooled ceiling
DV	Displacement ventilation
RH	Relative humidity (%)
TR	Tonne of refrigerant
ADP	Apparatus dew point
BPF	Bypass factor
CFD	Computational fluid dynamic
DAQ	Data acquisition system
ISO	International Organization for Standardization
PVC	Polyvinyl chloride
VAV	Variable air volume
HCFC	Hydro-chlorofluorocarbon
PMEC	Pre-cooling munters environmental control
DADV	Desiccant air displacement ventilation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

ABSTRACT

The heat generated within a closed space like office has increased drastically in recent years with the optimal use of the heat generated equipment such as computer, and other machines. As air conditioning is an inherently energy intensive process, so there is a need for devising more efficient system that would consume less energy while maintaining very comfortable condition for occupants inside. The desiccant air conditioning combined with chilled ceiling is a new concept of air conditioning system. This technique had been widely used in a number of European countries, however, similar the use of such system has not been reported to date in any humid tropical countries. With the aim of investigating the feasibility of such a system in Malaysian context, a climate chamber [4.25 m (L) ×3.75 m (W) × 2.7 m (H)] has been built in the Fluid Dynamic Laboratory of the Universiti Sains Malaysia wherein a desiccant dehumidifier combined with a chilled ceiling system has been installed. The system uses 100% ventilation air to maintain the freshness of air inside the chamber. The study aims at evaluating the relative performance of the above-mentioned hybrid system compared to conventional air conditioning system. The specific focus is in measuring energy consumption of the whole system. 4 experiments were conducted during the study with simulated heat loads of 0 W/m^2, 25 W/m^2, 62 W/m^2 and 100 W/m^2. The initial results show that such system is viable in Malaysia with the possibility of reduction of energy to the tune of 40% compared to the conventional system. However, more studies need to be conducted prior to large scale use.

ABSTRAK

Haba yang dijanakan dalam ruangan tertutup seperti pejabat telah meningkat dengan mendadak pada masa kini kerana terdapat penggunaan alatan yang menghasilkan haba seperti komputer, mesin photostat dan lain-lain. Oleh sebab penyamanan udara adalah proses yang bergantung kepada penggunaan dan perubahan tenaga, sistem penyaman udara yang lebih berkesan diperlukan untuk menyingkirkan haba dan menyediakan keadaan yang paling selesa kepada pengguna dalam kawasan tertutup. Sistem penyaman udara dengan gabungan pengering udara dan siling tersejuk adalah konsep baru yang sudah dikemukakan di benua Eropah. Namun, sehingga kini, penggunaan sistem tersebut belum lagi dilaporkan di negara-negara bercuaca tropikal. Untuk kegunaan penyelidikan sistem penyaman udara gabungan pengering udara dan siling tersejuk.di Malaysia, satu kebuk cuaca berdimensi 4.25 m (panjang) ×3.75 m (lebar) × 2.7 m (tinggi) dan dilengkapi dengan pengering udara dan siling tersejuk serta alatan penyelidikan telah dibinakan dalam Makmal Dinamik Bendalir di Universiti Sains Malaysia. Kebuk tersebut . Pengudaraan kebuk tersebut ialah 100% untuk memperolehi kesegaran dalam kebuk tersebut. Matlamat penyelidikan ini ialah perbandingan terhadap prestasi relatif sistem tersebut dengan sistem yang lama. Fokus utama eksperimen ialah terhadap penggunaan tenaga oleh keseluruhan sistem tersebut. 4 kali eksperimen telah dijalankan dengan kehadiran haba 0 W/m^2, 25 W/m^2, 62 W/m^2 dan 100 W/m^2. Keputusan ujikaji menunjukkan sistem ini boleh diaplikasikan di Malaysia dengan kemungkinan penjimatan penggunaan tenaga sebanyak 40% berbanding dengan sitem yang tradisional. Tetapi, lebih banyak eksperimen dan penyelidikan perlu dijalankan untuk pengaplikasian yang lebih luas.

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CHAPTER 1

INTRODUCTION

1.1 Background

Most air-conditioning systems operate by the used of forced air, where warm room air is re-circulated, chilled and returned into the space. In the modern office, increased use of computers and other heat generating equipment means that higher and higher heat loads need to be removed from the environment. To maintain comfort in these conditions, a greater volume of cooled air has to be supplied to the work area which, in turn, makes draught-free cooling increasingly difficult. The conventional air conditioning systems that are widely used in these days are very energy intensive.

While different buildings have different requirements, the most important requirement remains the well being of occupants. Proper control not only prevents problems associated with an unhealthy environment, it provides occupants with the best possible environment in which to work. Many factors, such as health, activity levels, clothing, and social situations influence the well being and productivity of building occupants. Environmental conditions that are influenced by environmental systems and controls can include: air temperature, air velocity, air turbulence, temperature distribution, air humidity, air quality, and temperature of surrounding areas, noise, and lighting, arrangement of the room (size, colour, and view). The most important requirement of any building, however, is the comfort of its occupants. While different air conditioning applications will suit different buildings, proper control is necessary in every situation - not only to prevent problems associated with an unhealthy atmosphere but to provide the best possible environment in which to work.

Radiant cooling, a new technology is introduced in recent years, which follows a different principle of cooling. The ceiling with water panels belong to a new type of equipment which is mainly used to provide the cooling of the buildings. Chilled water running through pipes bonded to the back of the ceiling panels or with chilled air passing through the panels. The ceiling panels function as heat exchangers between the heat loads in the room and the chilled water or air. The heat exchange occurs mainly via radiation or absorption and some also via convection. Heat generated inside the cooling space is radiated from the warm heat sources to the cooled ceiling. In a radiant cooled environment, computers, people and other heat sources radiate the heat to the cooler surface of the ceiling. As an added benefit, the occupants perceive the heat transfer via radiation as particularly comfortable.

In addition, cooling via convection also occurs when the room air is cooled as it flows beneath the cooling panels. The cooler air is heavier than the warmer air rising from the heat sources, which creates natural high volume, low-velocity air currents. Air that is supplied to the space to be air-conditioned is dehumidified by desiccant wheel and cooled by heat exchanger before reaching the space.

Investment capital and running costs for radiant cooled ceiling systems will be lower compared to conventional air-conditioning systems. Radiant cooling systems reduce energy consumption and lower energy cost. The temperature of the chilled ceiling is not lower than the dew point temperature, so it may have potential that downsizing the refrigeration system. Also minimal maintenance requirement and reduced floor-to-slab height is minimal are additional benefits. As a guide there is the possibility to gain one additional floor every ten floors in a building's structure. This system is well known and applied in Scandinavian countries, Switzerland and Germany.

The other distinct advantage of the hybrid system is the reduction in the use of ozone depletion products e.g. HCFC refrigerants. This system also can deliver many services in single system that may reduce the running cost. The beams can be used to deliver cooling, heating and fresh air requirements. Chilled ceiling system has been successfully applied for comfort conditioning throughout the United Kingdom and mainland Europe. The active chilled beams have utilized the very latest technology to deliver unrivalled levels of performance and flexibility. In recent years, interests in this air-conditioning system also increased in North America and in some Asian countries.

Besides the advantage of this hybrid system, some problem also arises that need to be encountered. Condensation is the main problem in the hot and humid Asian countries. In order to avoid the condensation problem that can lead to damage of the property, dehumidification is urgently required. Droplets of water may be a serious problem to the occupants or equipment inside the space. On the other hand, 100% of the cooling capacity cannot be met in humid tropical climates, where the cooling requirement is around 100W/m^2 for an office premise.

Displacement ventilation and chilled ceilings are thus complementary ventilation and cooling technologies that have the potential to provide better comfort, air quality and energy consumption than conventional systems. The project was thus conceived with the aim of developing such a system and to investigate its viability under humid tropical climate. As this is the first such system developed in any humid tropical countries, there is a need to operate the system and analyse its operational parameters. More specifically three different aspects were planned to be investigated in the overall research a) technical viability, b) relative energy performance, and c) ability to meet comfort requirement.

1.2 Scope

The specific scope of the present project is:

- To operate the system under varying simulated load conditions and monitor the operating parameters e.g. chilled ceiling temperatures, air temperatures at different strategic points in the enclosed environment, and velocity of air.
- To monitor the energy consumption of various components of the system,
- To liaise with other researchers investigating the comfort parameters inside the climate chamber.

CHAPTER 2

LITERATURE REVIEW

Radiant Cooling

The ceiling water panels belong to a new type of equipment which is mainly used to provide the cooling of office buildings. Well known in Scandinavian countries, Switzerland and Germany, this system is not so much used in France (J. Miriel et al, 2002). In early 1990s, chilled ceiling was first investigated in laboratory studies in European countries as an alternative air-conditioning system. Thereafter, the system started its applications combined with displacement ventilation systems. Radiant cooling systems separate the cooling and ventilation tasks of a building conditioning system. Chilled ceilings were used to take care of the cooling load and while displacement ventilator were set up as an independent ventilation system. There are 2 major buildings in Europe having successful chilled ceiling system. One is Zurich train station. North wing of main station had been completed in 1997. The air conditioning concept is based on the cooling ceiling technology. In the central part of the building, cooling ceiling elements with integrated lighting were installed in between concrete beams. This strategy enabled the building to be cooled without losing room height. The second building is Geneva's Blandonnet II. The Blandonnet II is a 237,000 ft2 (22,000 m^2) office building located right next to the Geneva Airport. (http://www.redec.com/pdf/introduction.pdf) The concept for the air conditioning system is based on the use of minimal quantities of fresh air. The ceiling was designed with a linear grid system that allows great flexibility.

Generally, there are many types of chilled ceiling such as chilled beams, cooling slabs, and cooling grids. However, the most widely used of the chilled ceiling in today is the water-cooled radiant panels built in dropped ceilings or so called as drop ceiling or T Grid type. Basically, radiant cooling ceiling panels contain chilled water running through pipes that are bonded to the non-visible side of the panels. The ceiling panels function as heat exchangers between the room air and the chilled water. Hydronic concrete slab cooling and heating systems can use relative high water temperatures for cooling and relative low water temperature for heating. This increases the possibility of using renewable energy sources like ground heat exchangers, solar energy for heating and cooling and free night cooling. It also increases the efficiency of boilers, refrigeration machines and heat pumps (Steimle, 1999). On top of that the slab system may use cheaper night rate electricity. When using surface a system for cooling it is important to control surface temperatures or water temperatures to avoid condensation. One possibility is to set a lower limit for the supply water temperature (Olesen, 1997a) to equal the dew point temperature.

The ceiling absorbs heat from heat sources in a room and exchanges it with the circulating chilled water. The chilled water is then pumped to a chiller, recooled, and returned to the ceiling (Fig. 2a).

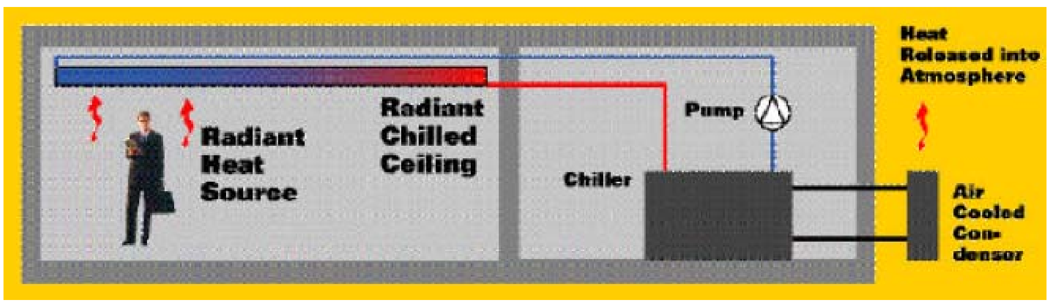


Figure 2a: Schematic of heat removal with radiant cooling ceilings (Source: http://www.climate-eu.invensys.com)

The heat emitted in the room is radiated from a warm body to the cool ceiling. As the ceiling is warmed, it conducts the heat through the ceiling to the chilled water. The water transports the energy to a chiller where the room heat is emitted to the outside environment.

The following are some of the major benefits claimed for radiant cooling ceiling systems:

- Maximum comfort for productive work environments.
- Draft-free, low-noise cooling even with high heat loads.
- Increased available floor surface.
- Smaller plenums and possibly additional floors per building.
- Minimal maintenance costs.
- Possible lower investment costs with heat loads greater than 11 - 14 BTU/ft^2 (35 - 45 W/m^2).

- Possible faster return on investment.
- Reduced energy consumption and lower energy costs.
- Architectural freedom.
- Problem- and malfunction-free operation.

Desiccant Cooling

Desiccant cooling is defined as the use of chemical or physical absorption of water vapour to dehumidify air and reduce the latent cooling load in a building heating, ventilating and air-conditioning systems. Supplementary refrigeration reduces air temperature. When air temperature is below the dew point temperature, humidity needs to be removed by the use of hygroscopic materials, which adsorb water vapour present in humid air. These hygroscopic materials are basically known as desiccants. Desiccant removes moisture from the surrounding air until they reach equilibrium with it. The transfer of moisture is due to the difference in vapour pressure at the desiccant surface and that of the surrounding air. When the vapour pressure at the desiccant surface is less than of air, the desiccant attracts moisture and releases it when its vapour pressure is greater than air. The main function of desiccant air-conditioning system has a main function to removes humidity from the ventilation air because latent cooling load can account for as much as 30% to 50% of air conditioning requirements.

Additionally, reducing humidity in the air handling system and the building space during the cooling season will improve indoor air quality by preventing condensation in equipment and reducing the growth and propagation of micro-organisms. Desiccant air-conditioning system is an extremely useful technology particularly in hot and humid climates and may also be used to reduce the load on air conditioning equipment in damper climates.

Hybrid Systems

A hybrid of desiccant air conditioning combined with chilled ceiling is one of the heating, ventilating and air-conditioning system that are popular for its ability to provide a high indoor air quality and thermal comfort. For this cooling system, desiccant cooling is efficient in providing latent cooling, whereas chilled ceiling is efficient for sensible cooling. Air dehumidification is needed to maintain the indoor air quality within a comfort zone and to reduce the problem of condensation on chilled ceiling panels. Malaysia, having a hot and humid climate country is ideal for this combination system.

In the combination air-conditioning system, displacement ventilation will develop the ventilation within the space, by blowing air from the floor level and exhausted the same at ceiling level. This will make sure the air in closed space is partially or fully ventilated according to the requirements. One of the distinct advantages is the temperature of the air supplied to the room is not much lower as conventional system. This can help to save a lot of energy to meet energy saving purposes.

Ameen and Mahmud (2004) have done a series of experiment about desiccant dehumidification combined with hydronic radiant cooling system for air conditioning application in humid tropical climates. An environmental chamber equipped with chilled ceiling system combined with desiccant dehumidifiers has been setup in the Fluid Dynamic Laboratory in Universiti Sains Malaysia. Their study present the design parameter for the hybrid system or the chilled ceiling combined with displacement ventilation system. This hybrid system is very suitable for air conditioning a space requiring high ventilation air supply.

Novoselac and Srebric (2001) from The Pennsylvania State University, USA did a review on the performance and design of combined cooled ceiling and displacement ventilation systems. This paper reviews the studies and design of cooled ceiling and displacement ventilation (CC/DV) systems in buildings. If properly designed, the combined CC/DV systems can provide better indoor air quality and thermal comfort level compared to the widely used variable air volume (VAV) mixing systems.

Loveday et al did a review titled: Displacement ventilation environments with chilled ceilings: thermal comfort design within the context of the BS EN ISO 7730 versus adaptive debate. This paper discuss about the applicability of the current standard when designing for the thermal comfort in offices equipped with chilled ceiling and displacement ventilation systems. The reported thermal comfort sensations were compared with value predicted from BS EN ISO 7730 over a range of operating conditions.

Olsen from Massachusetts Institute of Technology, USA, and Qinyan (Yan) Chen from Purdue University, USA (2002) have investigated the energy consumption and comfort analysis for different low-energy cooling systems in a mild climate. Results show that systems that maximize free cooling from outside air have the best energy performance, and that natural ventilation alone cannot provide year-round comfort in the building studied.

Fredriksson, Sandberg and Moshfegh (2001) from Sweden did an experimental investigation of the velocity field and airflow pattern generated by cooling ceiling beams. The results show that the airflow from the chilled beam has behaviours similar to a two-dimensional plume but exhibits strong oscillation both sideways and along the chilled beam. Furthermore, airflow generated by heat sources in the room may reverse the flow generated by the chilled beam.

Niu et al (2000) from Hong Kong Polytechnic University have run through the investigation of energy savings potential of chilled-ceiling combined with desiccant cooling in hot and humid climates. Comparison with another three systems: conventional all-air system, all-air system with total heat recovery, and radiant cooling with air handling unit (AHU), are considered for a typical office in Hong Kong. The results indicate that chilled-ceiling combined with desiccant cooling could save up to 44% of primary energy consumption, in comparison with a conventional constant volume all-air system. And, more than 70% of annual operating hours for desiccant regeneration could be accomplished by low-grade heat of less than 80 °C.

Miriel et al (2001) have written a thesis titled: Radiant ceiling panel heating–cooling systems: experimental and simulated study of the performances, thermal comfort and energy consumptions. This experimental study was carried out in laboratory, located in Rennes, in western France. A water ceiling panel system and a data acquisition system were installed in a test room. Simulation models were developed with the simulation program TRNSYS, using the experimental study results for the code verification.

Kitagawa et al from Toshiba, Air-Conditioners and Appliances Engineering Laboratories, Japan and Shin-ichi Tanabe from Ochanomizu University, Japan have do some researches about the effect of humidity and small air movement on thermal comfort under a radiant cooling ceiling by subjective experiments. Inside the climate chamber, subjective with sedentary activity exposed to the different humidity (45% RH, 65% RH, and 85% RH) and variable air movement during the investigation. The effects of the different condition are obtained from the sensation vote of the subjective. As a result, small air movement with radiant cooling system had possibility of improving the comfortable sensation votes in the radiant cooling.

L. Z. Zhang and J. L. Niu from Hong Kong Polytechnic University (2001) did a pre-cooling Munters environmental control desiccant cooling cycle in combination with chilled-ceiling panels. They found that desiccant cooling is efficient in latent cooling, whereas chilled-ceiling is efficient for sensible cooling. In this paper, a new desiccant cooling system, a pre-cooling Munters environmental control (PMEC) cycle is proposed, which combines with chilled-ceiling panels.

S. J. Rees (2001) from School of Mechanical and Aerospace Engineering, Oklahoma State University, USA and P. Haves from Lawrence Berkeley National Laboratory, USA discussed about a nodal model for displacement ventilation and chilled ceiling systems in office spaces. The discussion has been developed to represent room heat transfer in displacement ventilation and chilled ceiling systems.

Zmrhal et al (2003) from Czech Technical University in Prague have a paper that describes modelling and simulation of a space with radiant cooling ceiling (CC). Their main goal is to determine conditions of thermal comfort of occupants in a room with cooling ceiling and various heat gains. The paper also presents the influence of the room height on thermal comfort.

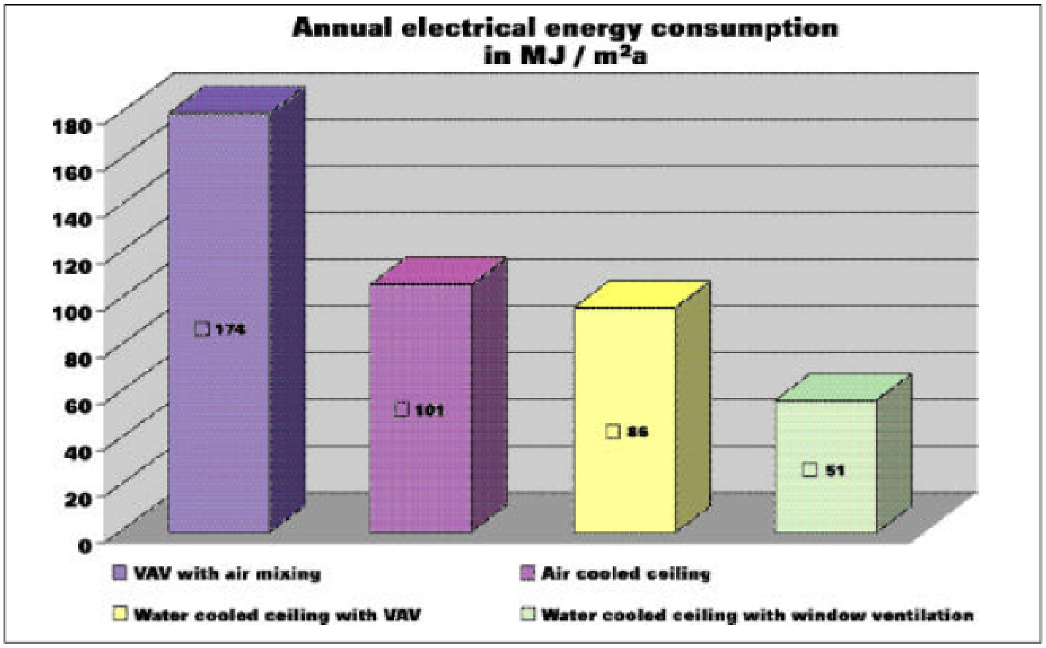


Figure 2b: Annual electrical energy consumption for different systems

In the above figure, the first column shows energy consumption with a conventional VAV system. Transporting more or less air into the room controls heat loads. The second column shows energy consumption when air is used as the cooling medium in an air-cooled ceiling. Chilled air is blown through special air channels in the aluminium ceiling profiles. The cooled ceiling absorbs the heat from the space below, warming the air flowing through it like a reheat before it enters the space, eliminating diffuser "dumping" and draft. Using as great a temperature differential as possible with a VAV system, less air mass is transported, saving transport energy. The third column shows consumption continuing to drop with a radiant cooling ceiling system that uses water as the cooling medium and VAV ventilation. The last column shows consumption in a pure radiant cooling ceiling application. The cool ceiling removes the total sensible heat loads, and fresh air is gained through window ventilation. Uncontrolled window ventilation has one major disadvantage. Heat recovery is not possible, and this has a negative influence on the total energy balance. As a rule, the more energy that is removed by the cooling ceiling, the more energy efficient the system is.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

3.1 Experimental Setup

For the experiment purposes, a set of facility has been developed at the Fluid Dynamic Laboratory in Universiti Sains Malaysia. The experiment facility includes:

(i) Chilled Water Circuit
(ii) Chilled Ceiling Panel
(iii) Climate chamber
(iv) Desiccant Air Displacement Ventilation (DADV) system
(v) Data Acquisition System

2 units of Watt hour meter and 2 units of water flow rate meter have been installed for recording the energy consumption and water flow rate of the different hardware. The facility has been designed suitable for various researches including the experimental verification of CFD simulation and area of thermal comfort.

3.1.1 Chilled Water Circuit

The chilled water circuit consists of an air-cooled chiller, with nominal cooling capacity of 11.72 kW (39.988 Btu/h) (3.3 TR) supplying chilled water to the chilled ceiling panel and air cooler (heat exchanger) downstream of the desiccant dehumidifier. A 3-way by-pass valve and a thermostat have been installed in the chilled water circuit to control the ceiling temperature. A by-pass chilled water supplies chilled water to the air cooler (heat exchanger), to bring down the temperature of the dehumidified air before it is supplied to the chamber. The schematic diagram of the combined system has been shown in **Figure 3.1a** below.

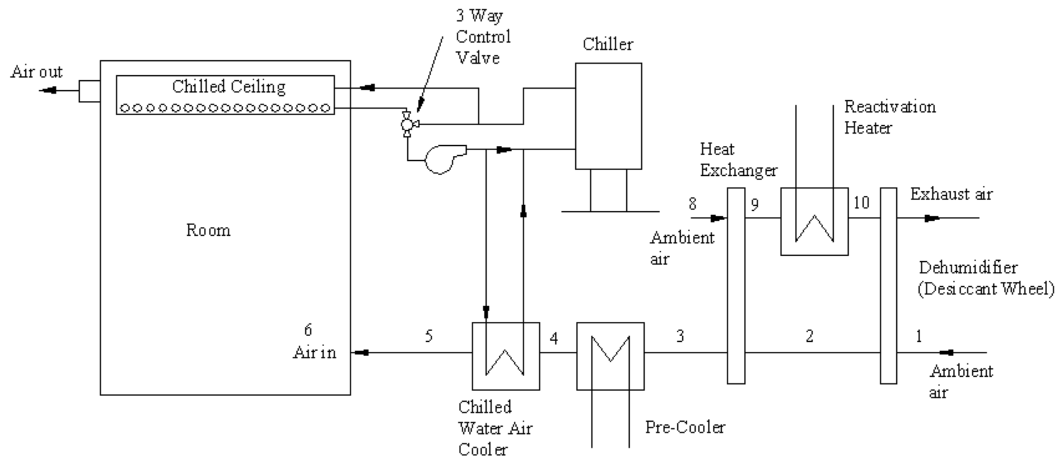


Figure 3.1a: Schematic diagram of the combined system

The various processes are represented in the schematic diagram shown above. The ambient air comes in from point 1 to the desiccant wheel. When the air passes through the desiccant wheel, the air is dehumidified and heated. After the air is dehumidified, it will pass through a pre-cooler to reduce its temperature. The pre-cooler is a heat exchanger that using water with normal temperature to reduce the temperature of the air. Then, again air will be directed to another heat exchanger which is chilled water air cooler to remove the heat of the air. This type of heat exchanger using chilled water from chiller to reduce the air temperature to meet the design specification before it is delivered to the climate chamber.

Photo 3.1a: Air-cooled chiller from Acson

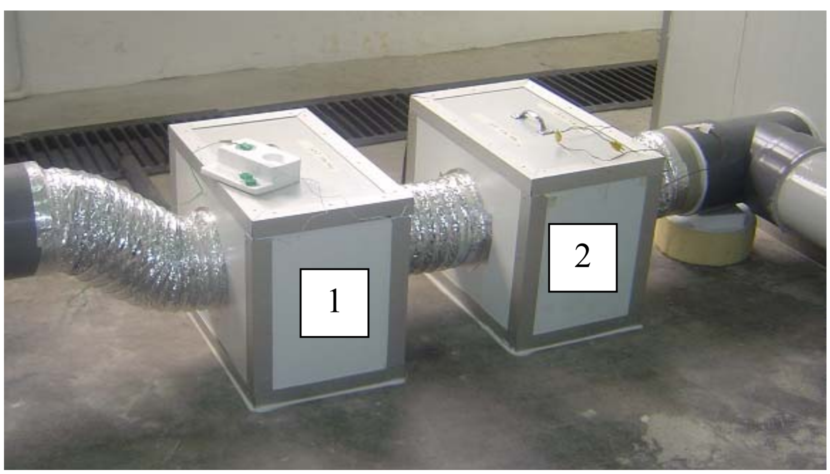


Photo 3.1b: Object 1: Pre-cooler

Object 2: Chilled water air cooler

3.1.2 Chilled Ceiling Panel

Drop ceiling or T Grid type and hanging element type are the 2 types of practices in chilled ceiling construction. The chilled water is directed flow through the tubes that embedded in the ceiling panel to maintain the surface temperature of the ceiling in the range of 16˚C-19˚C. Chilled ceiling can remove heat load up to 100 W/m^2 (31.71 Btu/h. ft^2) of floor area by the combined processes of convection and radiation. The hybrid system, chilled ceiling and displacement ventilation system, improve the thermal comfort oft the occupants inside chamber. Meanwhile, air quality can also be improved. In the present research the chilled ceiling system which has been set up in the climate chamber is of water-cooled drop ceiling type.

For the chamber that constructed for research, drop down type ceiling has been chosen. The chilled ceiling consists of 12 numbers of flat panels made of aluminium plates of thickness 1 mm (0.039 in) occupying 70% of the total ceiling area. Above the flat panel, there are copper tubes with 12 mm (0.468 in) diameter and 150 mm (5.85 in) spacing between the tubes. There are 2 headers providing chilled water to the individual panels through flexible tubes.

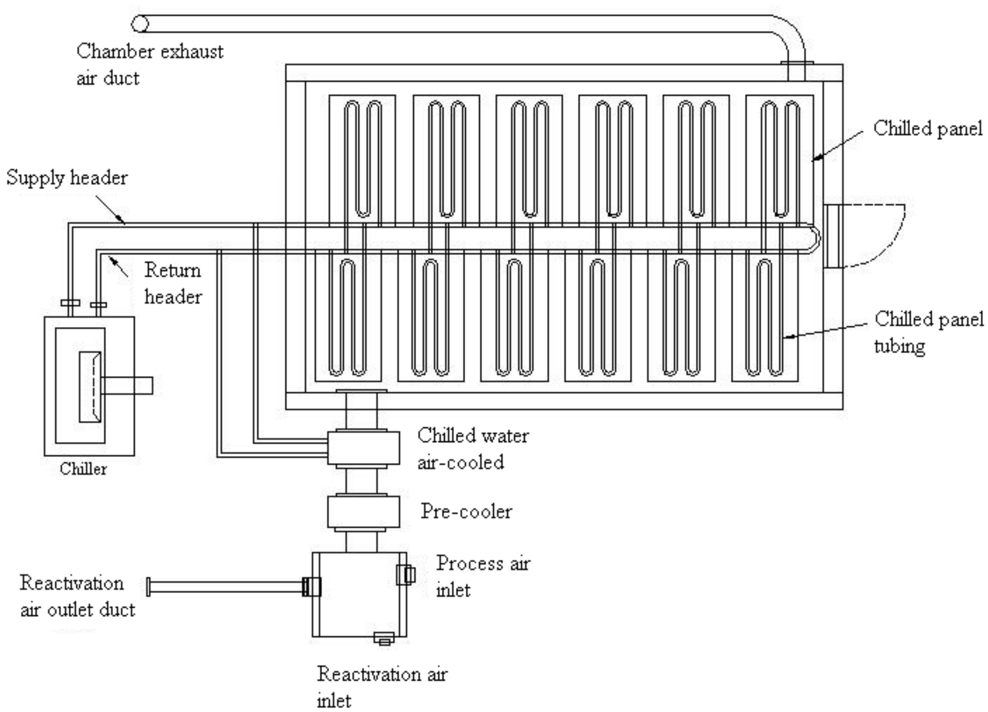


Figure 3.1b: Chilled water and air supply circuit.

Photo 3.1c: Drop down type ceiling

3.1.3 Climate Chamber

A climate chamber has been built and installed with chilled ceiling for conducting the research. The dimension of the chamber is 4.25 m x 3.75 m x 3 m (13.94 ft x 12.3 ft x 9.84 ft) with demountable clip-lock type insulated panels. The 100 mm (3.9 in) insulated panels are of galvanized steel sheets laminated to an insulation core of polyurethane. Dehumidified air is supply to the chamber combined with chilled ceiling system for the air conditioning purposes.

Photo 3.1d: Climate chamber

3.1.4 Desiccant Dehumidification System

Condensation will be a main problem for the application of the chilled ceiling combined with desiccant air conditioning system in the hot and humid climate region. Therefore, it is essential to use an independent and complementary air dehumidification system. Desiccant dehumidification system will be the most appropriate system for the dehumidification purposes. The desiccant wheel is supplied by the Bry-Air, which capacity is 600 cmh. A commercial silica gel desiccant wheel of fluted flat has been installed to provide dry air to the chilled ceiling chamber. The rotary type dehumidifier dries air with continuous physical absorption. The humid in the air is removed by the dehumidification sector by slowly rotating fluted, metal silicate desiccant synthesized rotor and is exhausted in the reactivation sector by a stream of hot air in the counter flow. Along with the reactivation process, the moisture absorbent is ready to absorb the moisture again. In the dehumidification process, there are 2 processes proceeding continuously and simultaneously, which is moisture absorption and reactivation process.

For the trial run measurement, the temperatures obtained are:

Table 3.1a: Condition of inlet and outlet air

Temperature	Dry Bulb	Wet Bulb
Inlet Air	32 ˚C (89.6 ˚F)	27 ˚C (80.6 ˚F)
Outlet Air	58 ˚C (136.4 ˚F)	28 ˚C (82.4 ˚F)

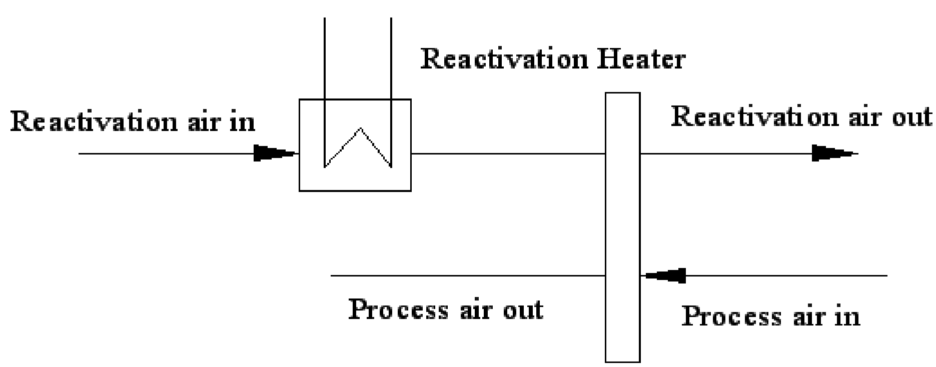


Figure 3.1c: Air dehumidification and regeneration process

Photo 3.1e: Desiccant wheel

<u>3.1.5 Data Acquisition System</u>

Data acquisition system (DAQ) is developed for automatic recording of temperature, mean radiant temperature, relative humidity and velocity at various locations in the climate chamber. The DAQ hardware comprises a Pentium processor based desktop computer, a data logger and data acquisition software. Thermocouples are used to record temperature simultaneously at 8 points of strategic grid in the climate chamber. With the automatic logging system, the tedious work and differential in timing of reading data can be rejected. Less error of data will be collected, if no heat source (human) inside the climate chamber.

Photo 3.1f: Data acquisition system

3.1.6 Other equipment/Instruments

There are 2 watt-hour meters and 2 flow meters are fitted to the air and water supply circuit. These meters are used to measure the water flow rate and energy consumption when different load is applied. A diffuser located inside the climate chamber to control the direction of the air. The air supply circuit is all constructed by the PVC pipes. Chilled water that supply to the chilled ceiling panel is connected by the insulated pipes to minimize the heat absorption of the water. There are some thermocouples and temperature recorders have been used for temperature measurement. The thermocouple is made of copper and constantan.

Photo 3.1g: Air diffuser

Photo 3.1h: Chilled ceiling temperature controller

Photo 3.1i: Watt-hour meter

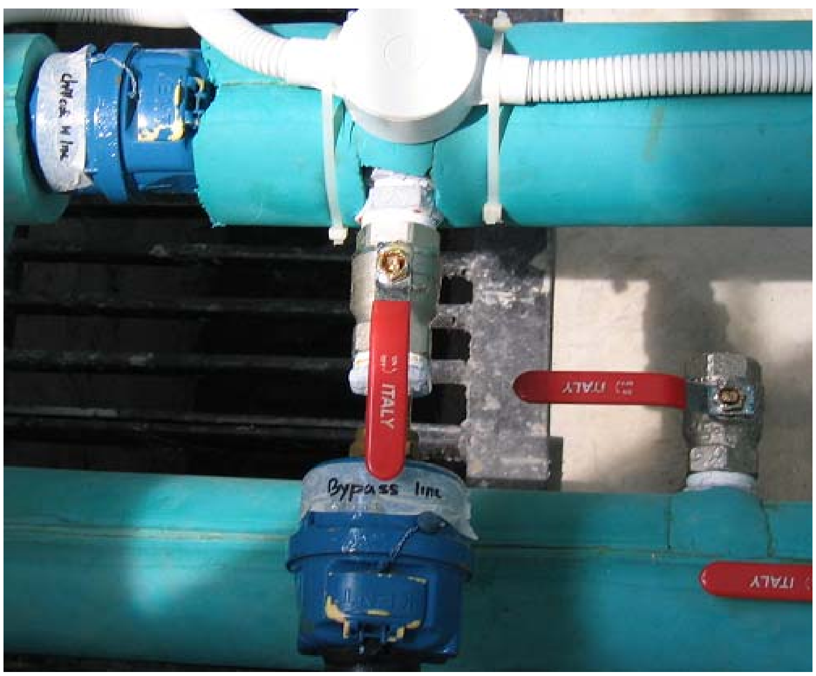


Photo 3.1j: Flow meter

3.2 Experimental Design

The experiments that conducted under the environmental chamber are classified into 4 groups. The conditions are tabled in following tables.

Table 3.2a: Experiment 1

Experiment conditions	
Heat load (W/m^2)	0
Air temperature (˚C)	21.02 – 23.05
Relative humidity (%)	22.2 – 70.5
Air velocity (m/s)	0 – 0.42
Ceiling panel temperature (˚C)	15

Table 3.2b: Experiment 2

Experiment conditions	
Heat load (W/m^2)	25
Air temperature (˚C)	22.47 – 24.35
Relative humidity (%)	29.7 – 50.3
Air velocity (m/s)	0 – 0.37
Ceiling panel temperature (˚C)	15

Table 3.2c: Experiment 3

Experiment conditions	
Heat load (W/m^2)	62
Air temperature (˚C)	22.28 – 29.07
Relative humidity (%)	29.4 – 51.5
Air velocity (m/s)	0 – 0.4
Ceiling panel temperature (˚C)	22 – 14

Table 3.2d: Experiment 4

Experiment conditions	
Heat load (W/m^2)	100
Air temperature (˚C)	24.31 – 26.04
Relative humidity (%)	47.5 – 57.8
Air velocity (m/s)	0 – 0.46
Ceiling panel temperature (˚C)	15 – 16

3.3 Experimental Methodologies

There are some experimental procedures have to do before, during and after the experiment. First, the heat load inside the chamber must be known. Then, temperature of the air inside the chamber and ceiling panel temperature have to be measured. The temperature of the air at reactivation inlet and outlet of the dehumidifier, temperature of air at process inlet of the dehumidifier and the temperature of the air before and after heat exchanger 1 and 2 must be measured every 10 minutes.

There is a data acquisition system inside the chamber. It must be set so that it can obtain data automatically every 10 seconds. The data that can be recorded are air temperature, relative humidity, air velocity, mean radiant temperature, dew point temperature and wet bulb temperature. The data obtained are to be processed by the computer for further usage. Outside the chamber, the readings of the kilowatt meter for desiccant dehumidifier and chiller, flow rate meter of the chilled water and bypass line are taken every 10 minutes.

After all the data are recorded, comparisons between the Desiccant Air Conditioning Combined with Chilled Ceiling and the conventional system can be made. Meanwhile, the comfort parameters of the Desiccant Air Conditioning Combined with Chilled Ceiling need to be found out for design purposes are air velocity, relative humidity, dry bulb temperature, and mean radiant temperature.

3.4 Experimental Procedures

1. Four different experiments were conducted to obtain energy consumption data for the chilled ceiling combined with displacement ventilation system. Heat loads are predetermined before the experiment, which were 0 W/m^2, 25 W/m^2, 62 W/m^2 and 100 W/m^2.
2. Ventilation air that is supplied to the climate chamber passed through the desiccant wheel, where moisture is removed with consequent rise in temperature. Thereafter the same air passes through two heat exchangers. In the first heat exchanger air is cooled by tap water at around ambient temperature flowing through cooling coils. In the second heat exchanger, cooling is effected by chilled water tapped from the chilled water supply line. The purpose of the two heat exchangers is to pre-cool the desiccated air
3. To monitor comfortable condition within a closed space, the following parameters were considered - dry bulb temperature, relative humidity, and air velocity.
4. In tropical country, condensation of water is the main challenge to implement the chilled ceiling system to the real world. This is because water will damage the equipment and cause discomfort to the occupants. To avoid this problem, humidity of the air needs to be controlled by using an air dehumidifier.
5. When using surface systems for cooling, it is important to control surface temperatures or water temperatures to avoid condensation. One possibility is to set a lower limit for the supply water temperature to equal the dew point temperature. If the humidity is not controlled, the cooling capacity may be further reduced in order to avoid surface condensations.
6. The supply air is preconditioned to obtain a supply air temperature lower than the space temperature and remove latent loads by dehumidification. In this way the humidity, i.e. the dew point, will be controlled and the performance of the radiant cooling systems is then increased.

CHAPTER 4

RESULT AND DISCUSSION

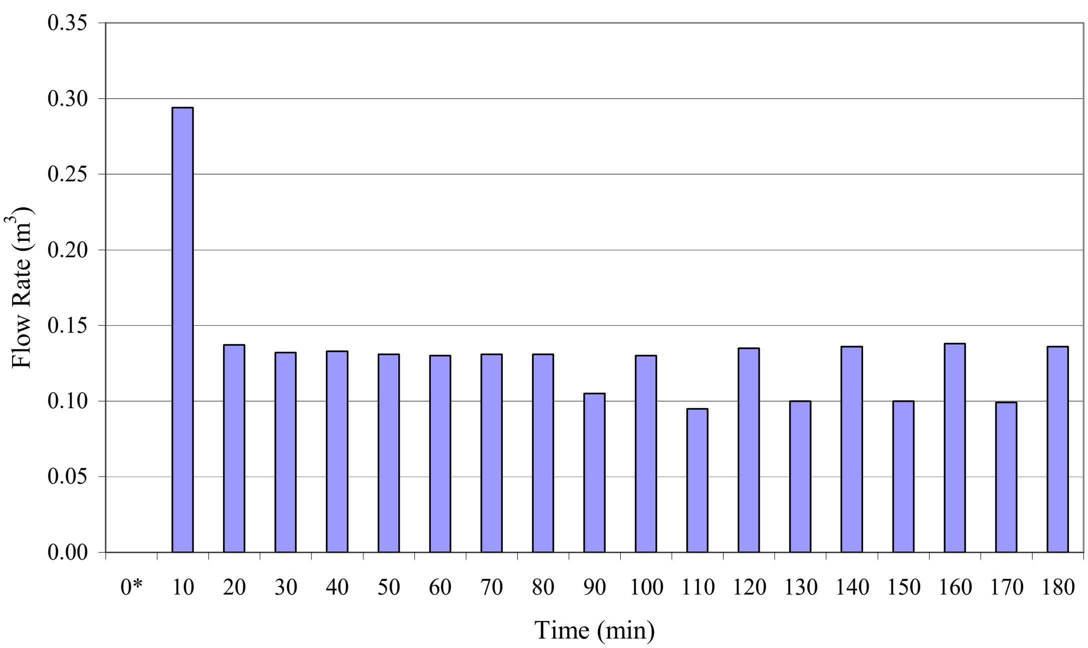
While discussing the performance of this hybrid air conditioning cycle two specific aspects need to be reviewed – i) the performance related to energy efficiency and ii) performance related to the ability to maintain comfort.

Energy Performance

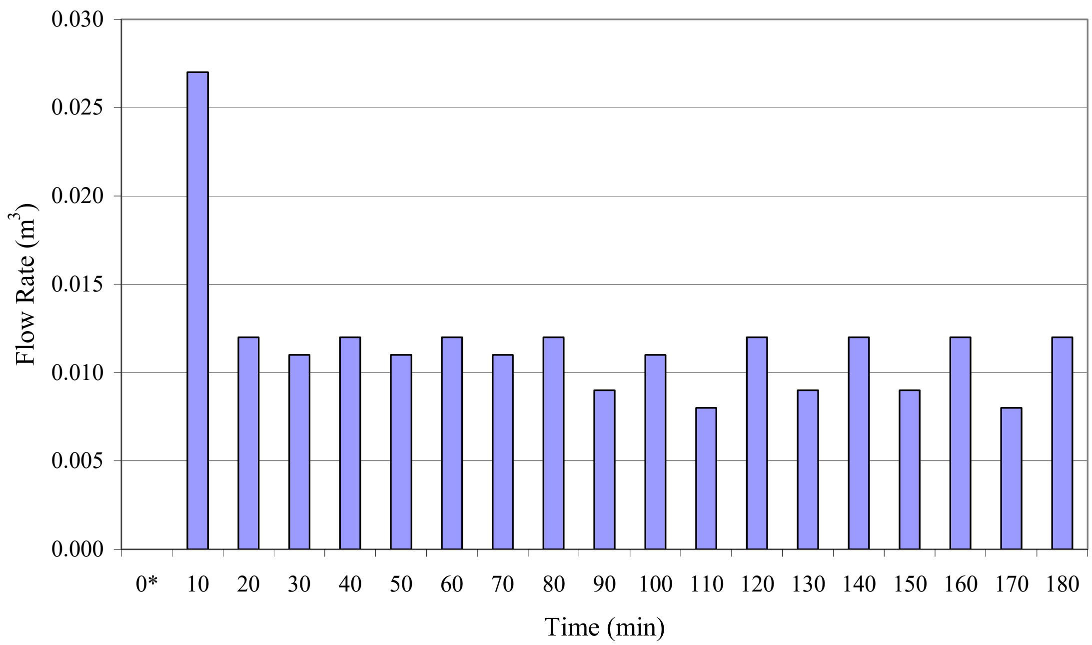
Graphs of 0 W/m^2:

i. From Graph 1a and 1b, it can be observed that the water flow rates of chiller and the bypass lines have higher flow rates at first interval (10 minutes) then it will decrease and remain almost constant for remaining intervals.

Graph 1a: Chiller Water Flow Rate VS Time (0 W/m^2



Graph 1b: Bypass Line Water Flow Rate VS Time (0 W/m²)



ii. For the desiccant wheel, the energy consumption is almost constant throughout the 3 hour period (Graph 1c). It runs constantly to supply dehumidified air to the climate chamber. Energy consumption for chiller (Graph 1d) may fluctuate because chiller will stop when the supply water temperature is low enough and it will restart when water temperature increase. Hence, although an average temperature of supply water may be maintained according to preset value, fluctuation in supply air temperature cannot be avoided.

iii. This is one of the operational problems that need to be addressed to by increasing chiller load.