HUMIDITY CONTROL IN DIFFERENT BUILDING APPLICATIONS; RESTAURANT AND OPERATION THEATRE

MOHD SYAFIQ SYAZWAN BIN MUSTAFA

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Universiti Tun Hussein Onn Malaysia

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For my beloved mother and father

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ABSTRACT

Air conditioning (AC) in tropical climate required dehumidification of air at a low dew point temperature to meet humidity standard. This increase the required cooling energy and heating energy is needed to raise the supply air temperature to meet the room's design temperature. This research was carried out to study energy efficiency and indoor environment factor in two different applications that is restaurant and operation theatre (OT). A method was proposed to enhance the humidity control and energy efficiency in the AC system by applying psychrometric analysis based on actual measurement. Three (3) different systems were used in this study that consists of economizer damper, desiccant wheel and heat pipe heat exchanger (HPHX).The economizer damper analysed base on fresh air intake requirement for ventilation purposes on standard ASHRAE 55 (2010). Manufacturing software by Novelaire and HPC were used to perform the psychorometric analysis for desiccant wheel and HPHX. At the restaurant, the grand total loads (Qt) of the existing AC system were 296.1 kW as to meet temperature and humidity level requirement. The Qt was reduced to 153.8 kW for economizer damper, 170 kW with heating 60.38 kW for desiccant wheel and 178.3 kW with heating 4.1 kW for HPHX. In actual measurement for the OT, the existing AC system had a grand total load Qt of 90.1 kW with heating 5.6 kW and it did not meet the humidity level requirement. However, the AC system required Qt 95.9 kW with heating 12.2 kW as to meet the humidity level requirement for an OT. By using the HPHX in the system, a reduced Qt of 81.6 kW with heating 17.7 kW was achieved, where as a Qt of 100.8 kW with heating 39.9 kW was attained by utilizing the desiccant wheel, whilst maintaining the humidity level requirement. The economizer damper was not applicable for the OT because the OT requires 100% fresh air intake. As a conclusion, damper economizer was beneficial for energy efficiency in restaurants with reducing of 48% energy used and HPHX was beneficial for energy efficiency with reduced 9.4% in OT compared with existing AC system.

ABSTRAK

Sistem penyaman udara (AC) di dalam iklim tropika memerlukan udara dikeringkan di suhu titik embun yang rendah. Ia meningkatkan tenaga sejuk dan pemanasan diperlukan untuk meningkatkan semula suhu udara. Kajian ini dilakukan untuk mengkaji aspek kecekapan tenaga dan faktor persekitaran dalaman pada aplikasi yang berbeza. Penyelidikan ini mencadangkan untuk meningkatkan kawalan kelembapan dan kecekapan tenaga sistem AC dengan penggunaan analisis psychrometric berdasarkan pengukuran yang sebenar. Tiga (3) sistem yang berbeza digunakan dalam kajian ini iaitu penjimat peredam, roda pengering dan penukar haba jenis paip (HPHX), kajian ini dijalankan ke atas dua (2) aplikasi yang berbeza di restoran dan dewan bedah (OT). Penjimat peredam menganalisis keperluan pengambilan udara segar untuk orang berdasarkan standard ASHRAE 55 (2010). Perisian perkilangan dari Novelaire dan HPC digunakan untuk psychrometic analisis bagi roda pengering dan HPHX. Di restoran, jumlah beban besar (Qt) sistem AC yang sedia ada adalah 296.1 kW bagi memenuhi keperluan suhu dan kelembapan. Qt telah dikurangkan kepada 153.8 kW bagi penjimat perendam, 170 kW dengan pemanasan 60.38 kW bagi roda pengering dan 178.3 kW dengan pemanasan 4.1 kW bagi HPHX. Sementara itu, sistem AC yang sedia ada pada OT mempunyai jumlah beban besar Qt 90.1 kW dengan pemanasan 5.6 kW tetapi tidak memenuhi keperluan tahap kelembapan. Sistem AC memerlukan Qt 95.9 kW dengan pemanasan 12.2 kW untuk memenuhi keperluan tahap suhu dan kelembapan. Dengan menggunakan HPHX, Qt dikurangkan kepada 81.6 kW dengan pemanasan 17.7 kW, dan Qt roda pengering adalah 100.8 kW dengan pemanasan 39.9 kW. Peredam penjimat tidak boleh diaplikasikan bagi OT kerana OT memerlukan 100% pengambilan udara segar. Kesimpulannya, peredam penjimat memberi manfaat untuk kecekapan tenaga di restoran dengan pengurangan sebanyak 48% dari tenaga yang digunakan dan HPHX memberi manfaat untuk kecekapan tenaga dengan pengurangan sebanyak 9.4% pada OT berbanding dengan sistem AC yang sedia ada.

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LIST OF SYMBOLS

Δh	-	Differential enthalpy (kJ/kg)
Δt	-	Differential temperature (ºC)
$\Delta\omega$	-	Differential humidity ratio (kg/kg)
A	-	Area (m^2)
$\dot{m}$	-	Mass flow rate (kg/s)
RH	-	Relative humidity (%)
V	-	Volumetric flow rate (m^3/s)
v	-	Specific volume (m^3/kg)
v	-	Velocity (m/s)
ω	-	Humidity ratio (kg/kg)

LIST OF ABBREVIATION

AC	-	Air Conditioning
AHU	-	Air Handling Unit
ASHRAE	-	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAS	-	Building automation system
CLF	-	Cooling Load Factor for people
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
ICOP	-	Industry Code of Practice
DF	-	Dehumidification fraction
DOSH	-	Department of Safety and Health Malaysia
EER	-	Energy efficiency ratio
FA	-	Fresh air
HPHX	-	Heat pipe heat exchanger
HVAC	-	Heating ventilation and air-conditioning
IAQ	-	Indoor air quality
MA	-	Mixing air
MVAC	-	Mechanical ventilation air conditioner
N	-	Number of people
OA	-	Outside air
OT	-	Operation Theatre
Q_L	-	Latent loads
Q_S	-	Sensible loads
Qt	-	Grand total loads
RA	-	Room air

RA’	-	Return air
RES	-	The rate of energy saving
ADW	-	After desiccant wheel air
SA	-	Supply air
SA’	-	After Heater Supply Air
RSHF	-	Room sensible heat factor
SHR	-	Sensible heat ratio
SMACNA	-	Sheet Metal and Air Conditioning Contractors' National Association
T&C	-	Testing and commissioning
VAV	-	Variable air volume
VC+D	-	Vapours compression and desiccant
VC+D+EC	-	Vapours compression, desiccant and direct evaporative cooler

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CHAPTER 1

INTRODUCTION

This chapter discusses the background of the research problem. It generally describes about the air conditioning (AC) systems and the importance of humidity control. This chapter also highlights the problem statement based on the background provided as well as the objectives, limitation and the significance of the study.

1.1 Background of Study

Air conditioning (AC) systems typically provides thermal comfort and good indoor air quality (IAQ) achieved by controlling the temperature, humidity level and cleanliness of the air distribution. Moreover the design of the AC system involves calculation of peak cooling loads, specification of system, calculation of annual performance and calculation of cost (Sekhar and Tan, 2009). On the other hand, the cooling loads estimation is very important to ensure proper removal of building heat loads. Building heat loads can be simply defined as internal and external loads. External loads occur due to heat transfer between the building and its' surroundings and it is affected by outdoor conditions whereas internal loads are contributed by occupants, lighting and appliances. In modern commercial buildings, the leading sources of cooling loads are internal loads (ASHRAE, 2009; Mcquiston, Parker and Spitler, 2011).

The AC system was designed with cooling coils and the ability to cool and dehumidify the air as well as to meet sensible and latent heat loads in typical buildings or rooms. Sensible heat load arises from dry bulb temperature. The sensible loads gains directly to the conditioned space by conduction, convection and radiation. Latent loads arises from moisture generated either from internal sources or from outdoor air ventilation to maintain the IAQ requirement (Burdick, 2011). Generally, comfortable indoor temperature is between 23 to 26 degree Celsius (°C) and relative humidity (RH) level is 40% to 70% (Malaysia Standard MS1525, 2010).

1.2 Problem Statement

The AC system typically cools and dehumidifies the air to provide comfortable indoor environment by removing sensible (temperature) and latent (moisture) loads. When the latent loads are high due to ventilation, wet surface and occupants, dehumidifying leads to reheating in order to meet the required indoor temperature and humidity level for comfort and health. The fresh air ventilation present in the AC system functions to improve the IAQ in the building and in special rooms, such as operation theatres and isolation rooms, as it needs 100% fresh air ventilation, a requirement to prevent microorganisms production in the rooms. It is a challenge for an engineer to design an AC system with a large outside air intake in tropical climate. To be specific, it is a common case in Malaysia where the weather is warm and humid all year-around with the average daily temperature ranging from about 30°C to 35°C and relative humidity (RH) is about 70% to 90% (Kosravi Salman et al, 2010).

The humid air coming from the fresh air ventilation may increase the sensible and latent load corresponding to the cooling energy consumption. The cooling coil needs to cool down the air at a lower dew point temperature for moisture removal and additional heating is required to meet the temperature before it is supplied to the room. Improper analysis of the dehumidification process for the AC system may lead to high cooling energy and thus affecting the RH in indoor environment. Cooling coils in the AC system requires extra energy and this causes inefficiency in the system. In terms of IAQ, RH must follow the standards for health and comfort reasons. High RH may lead to uncomfortable and stuffy conditions, while low RH will lead to the occupants complaints such as dry nose, throat, eyes and skin (Lstiburek, 2002). High RH levels will also lead to mold and fungus growth and affects the IAQ inside the building. These microorganisms spores travel by air and cause infectious diseases, allergies and other respiratory irritations to occupants (SMACNA, 1998). A major concern on energy conservation has led to the development of energy efficiency of the AC systems while improving indoor air quality in the buildings.

1.3 Objective of Study

This study concerns about the energy efficiency and indoor environment factor of the buildings or rooms that had been selected. The objectives are:

i. To investigate optional humidity control in tropical climates to meet the standard humidity level in two different latent heat loads applications.
ii. To compare cooling energy between the existing design and alternative supplementary design to maintain humidity standard requirement.

1.4 Scope of Study

The scope of the study began with the identification of high latent heat building or room. Latent loads are known as moisture loads that comes from outside air ventilation, humans, infiltration, equipment and appliances. Therefore, indoor monitoring was conducted in several rooms or buildings and was compared to Malaysian standard MS1525, Department of Safety and Health (DOSH) Malaysia and ASHRAE standard 55. Point of samplings followed the guideline from the Industry Code of Practice (COP) on Indoor Air Quality 2010, DOSH Malaysia. The minimum number of sampling is 1 point per 500 m^2. The indoor monitoring involved the air temperature, relative humidity (RH), carbon dioxide (CO) and carbon monoxide (CO_2) in the rooms that needed to be monitored. The information is required from the building owner in this study in order to understand the cooling load of the AC system that was installed include:

i. Technical data
ii. Testing and commissioning (T&C) report (if permitted)
iii. Design layout of the AC system
iv. Building automation system (BAS) daily (if any)

v. Civil and structure layout
vi. Control system
vii. Schedule maintenance
viii. Indoor air design requirement

The AC system performance was also monitored to identify the average cooling energy consumption in standard operations. The air flow rate was measured to obtain the actual total air flow rate of the AHU (field measurement). The ASHRAE recommendation for measuring air flow rate is at least 25 points for a rectangular duct (ASHRAE, 2009). The psychrometric chart was used to analyze the actual cooling energy required and to identify the latent and sensible loads respectively. The causes of both loads were rectified from the field test measurement for the AC system and indoor monitoring.

The improvement in dehumidification is a value added to the energy efficiency for the AC system and would further improve the indoor air quality in the building.

i. Economizer damper
   - Utilizing minimum fresh air intake results in huge energy savings in humid climate. The economizer damper can be useful in controlling outside air flow rate and to minimize the fresh air load.
ii. Desiccant Dehumidifier
   - Desiccant reacts by attracting and removing moisture from one stream to another and can be cost-effective because it uses low grade thermal sources to remove moisture.
iii. Heat pipe heat exchanger (HPHX).
   - HPHX is a high performance heat transfer device which works using evaporation and condensation sections of proper working fluid in individual closed tubes. Literature review on the studies, technology and application of desiccant and HPHX dehumidifier was conducted as supplements to improve the AC system.

The target area for this study was:

i. Restaurant
ii. Hospital Operation Theatre (OT)

1.5 Limitation of Study

The limitations of this study occurred due to the following components:

i. Gathering information at the selected buildings or rooms. Some information cannot be given to a third party because it is private and confidential to the engineering department of the selected buildings.

ii. Hot and humid climate play an important role in this study for the cooling and dehumidification process in the AC system. Due to the changes in the weather cannot be controlled.

1.6 Significance of Study

The comparisons of the proposed methods in the system are beneficial to HVAC consultants and engineers in order to improve the existing system and to properly design the air-conditioning system for energy efficiency. Three methods for improving humidity had widely been studied and used in industry which are for humidity improvement for good dehumidification, energy saving and healthy indoor air quality in a tropical climate buildings.

CHAPTER 2

LITERATURE REVIEW

In this part of the chapter, it will review the current status of the several studies that had been carried out on humidity control in different building applications in term of air-conditioning system, psychrometric chart overview, humidity control, humidity to indoor air quality (IAQ), desiccant dehumidifier technology that available, heat pipe heat exchanger (HPHX), the technology for dehumidification. Others operating conditions that can be used to optimize the performance of the humidity control in building system as well as additional relevant information of the study are taken as references.

2.1 Air-conditioning System

The Air-Conditioning (AC) system is a common system providing cooling and dehumidification process for typical buildings in a tropical climate. It comprises consists of the circulation air, exhaust and fresh air for air side and blower fan, motor, filter and cooling coil for mechanical components (Carrier, 1952).

Figure 2.1 shows the air side of the AC system which is known as the air handling unit (AHU). The cooling coil in the AHU handles the cooling and dehumidification process. The air contacts with the cooling coil surface and the moisture was condensate when the air is cooled below the dew point temperature. The air changed its state from water vapour to liquid water when it contacts with the cool surface. The liquid water is then drained away for disposal.

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