UNIVERSITI PUTRA MALAYSIA

COMPARISON OF COOLING COST EFFECTIVENESS BETWEEN UNITARY AND CENTRAL COOLING SYSTEM

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia
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Abstract of thesis presented to the Senate of University Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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February 2005

Chairman : Thamir Sabir Younis, PhD

Faculty : Engineering

Air conditioning is a basic need in building spaces to provide indoor comfort. This research describes the evaluation of cooling cost effectiveness between unitary and central chiller cooling system. Operational cost involving initial, energy and maintenance for both systems was analysed throughout the life span period. A case study was carried out where cooling load requirement of all conditioned spaces was determined using cooling load temperature difference / cooling load factor method. Currently in-use unitary system data was gathered and an all-water type central cooling system was proposed as an alternative. Main equipment capacity of the central system was designed based on cooling load and appropriate heat equation. The study shows that the central system is the better option for high air conditioning application of more than 60 kW heat gain. Although central system first cost is almost double than that of unitary system, it has the advantage of much higher life span. Cumulative cost analysis for the case study indicates that the investment of central system provides a payback period of eight years. In addition, the central system also contributes towards energy conservation by offering lower total power input of its equipment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERBANDINGAN KOS PENYEJUKAN BERKESAN DIANTARA SISTEM UNIT DAN BERPUSAT

Oleh

AZIZUDDIN ABD AZIZ

Februari 2005

Pengerusi : Thamir Sabir Younis, PhD

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Sistem pendingin hawa adalah satu keperluan asas untuk keselesaan di dalam bangunan. Kajian ini mengupas penilaian keberkesanan kos diantara sistem unit dengan system penyejukan *chiller* berpusat. Kos operasi melibatkan modal awal, tenaga dan penyelenggaraan telah dianalisis untuk keseluruhan jangka hayat kedua-dua sistem. Satu kajian kes telah dijalankan di mana beban penyejukan di semua bangunan telah ditentukan dengan mengggunakan kaedah *cooling load temperature difference / cooling load factor*. Data untuk sistem unit yang sedang digunakan telah dikumpul dan sistem berpusat jenis semua-air telah dicadangkan sebagai alternatif. Kapasiti peralatan utama sistem berpusat telah ditentukan berdasarkan beban penyejukan dan persamaan haba yang berkaitan. Hasil kajian menunjukkan bahawa sistem berpusat merupakan pilihan yang lebih menguntungkan untuk penggunaan pendingin hawa yang mempunyai beban penyejukan tinggi melebihi 60 kW. Walaupun modal awal sistem berpusat adalah sekali ganda sistem unit, namun ia mempunyai kelebihan jangka hayat yang lebih lama. Analisis kos keseluruhan untuk kajian kes menunjukkan bahawa pelaburan untuk sistem berpusat akan memberikan pulangan selepas lapan tahun. Sistem berpusat juga menyumbang ke arah penjimatan tenaga dengan menawarkan peralatan yang meggunakan jumlah kuasa masukan yang lebih rendah.

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I certify that an Examination Committee met on 14th July 2005 to conduct the final examination of Azizuddin Abd Aziz on his Master of Science thesis entitled "Comparison of Cooling Cost Effectiveness Between Unitary and Central Cooling Systems" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

AZIZUDDIN ABD AZIZ

Date: 21/2/2005

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NOMENCLATURE

λ	inflation rate
ν	ventilation (L/s)
BF	ballast factor
C	specific heat of water (kJ/kg°C)
CLF	cooling load factor
$CLTD_C$	corrected cooling load temperature difference (°C)
DR	daily range (°C)
FC	future cost of a commodity (RM)
PC	present cost of a commodity (RM)
LM	latitude and month correction (°C)
m	mass flow rate (kg/s)
Q	cooling load (kW)
Q_l	latent cooling load (kW)
Q_s	sensible cooling load (kW)
q_l	latent heat gain per person (kW)
q_s	sensible heat gain per person (kW)
R	heat resistance (m^2.°C/W)
RH	relative humidity
SC	shading coefficient
SHGF	solar heat gain factor (W/m^2)
T_O	outside air temperature (°C)
T_r	room air temperature (°C)
U	heat transfer coefficient (W/m^2.°C)
W_o	outside air humidity ratio (kg/kg d.a)
W_r	room air humidity ratio (kg/kg d.a)

CHAPTER 1

INTRODUCTION

1.1 General

Air conditioning could be defined as the process of treating air in an internal environment to establish and maintain required standards of temperature, humidity, cleanliness and motion (Pita, 2002). It is a system to transport heat and moisture out of conditioned space, despite any changes in outdoor weather conditions. Heat enters the conditioned space from multiple sources and must be removed at the same rate in order to maintain comfortable condition. In usual practice, the moisture transport is associated with dehumidification of an air stream by condensation. Thus, the moisture transport can also be included as a heat transport process allied with the phase change which is called the latent heat. Cooling process also function to ventilate conditioned spaces, diluting indoor contaminants with filtered outdoor air (Flake, 1998). As the outside environment sometimes contaminated by haze, open burning, industrial smoke etc., it is advisable to spend more time indoors. In this case, building acts as protective shelter and it is important to provide a descent air comforting system.

Zhang et. al (1999) acknowledged that the energy consumption of air conditioning will increase further in the next century with the increase of floor area and the air conditioning hours. The statement is undeniable as the population of the world is increasing and more premises will be constructed. Therefore, providing a healthy indoor condition has become a major factor in the quality of life. Bigger conditioned floor area also leads to bigger consumer demands. This enable the market of air conditioning products to becoming bigger each day which enable the manufacturer to gain profits after profits, where more budgets could be allocated for more research and development activities. Engineers would come out with ideas that innovative enough to create new system for indoor comfort while in the same time maintaining a low cost. With the increase in technology, many cooling systems are available in the market, giving the options to the consumer to choose based on specific requirement and purpose.

1.2 Problem Statement

Cost of air conditioning is always the first topic that comes to mind before making the selection of a cooling system. There is an old school of thought that suggests air conditioning cost is defined as the initial price of equipment plus installation. This misconception leads to many faulty judgements in the selection of a cooling system. Long term analysis of the cost is not taken into accounts, such as all possible charges involved in running the system and the expenses in keeping the equipment in good shape. In many occasions, the lifetime estimation of the system is not in consideration. As a result, the final decision is made in an unfair manner.

Any cooling system requires energy as the input to drive its equipment and sub-systems, before delivering the output in terms of cool air. For an office building, as described by Pita (2002), cooling activity consumes about 75% of total energy consumption, which makes it the highest user. In comparison, residential building requires lower share of power input at 40% of total requirement (Parker et. al, 1998). Masiello (2000) suggest even lower cooling energy consumption at 33% for household consumer. From these figures, it is clear that should there be any attempt to tackle the issue of energy consumption in commercial premises, air conditioning should be the first target. Pro-active measures have been taken in developed countries on this issue. For instance, in the United States there are building codes that require the developers to conform to in terms of heating, ventilation and air conditioning (HVAC) performance efficiency. The objective is simple, to minimise energy consumption. Such building code is yet to be implemented in this country and most part of the world. However, it does not mean that the energy issue could be taken for granted. Engineers are responsible to ensure that the most suitable air conditioner is installed in premises. As the energy usage for cooling system is significant, it is necessary for it to be kept at the minimum level.

In order to evaluate the effectiveness of an air conditioning system, a sample of cooling application had been selected in the scope of Faculty of Engineering, Universiti Putra Malaysia. At the time of study, the buildings were equipped with unitary system type of cooling better known as split unit. As unitary system is actually meant for low cooling load practices, concerns arise on the suitability of the application in the premises. Therefore, a comprehensive research on the cooling cost effectiveness needs to be performed.

1.3 Objectives

The goal of this study is to analyse cooling cost effectiveness through. The objective is achieved through cooling load calculation of a case study and the comparison between currently in-use cooling system against a suitable alternative air conditioning. The evaluation is based on appropriate assessment criteria to ensure fair appraisal being carried out.

1.4 Thesis Organization

The dissertation was divided into six chapters and four appendices. Chapter 2 gives an introduction to the principles of refrigeration and heat transfer as well as the philosophy of system design and cooling load. Types and characteristics of cooling system are briefly discussed together with the main equipment explanation. Chapter 3 describes the cooling load calculation according to a recognised method while Chapter 4 carries out the comparative analysis of evaluated air conditioning systems. The assessment is based on selected criteria and the outcome of appraisal is discussed in the end. Chapter 5 summaries the findings of the thesis and identifies potential areas of further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Since the creation of an equipment to restore internal comfort called the air conditioner long time ago, the urban lifestyle of modern mankind had changed drastically. Spending quality time indoor had been regarded as leisure, thanks to the temperature control and ventilation provided by the cooling system. In the meantime, the impact of air conditioning in terms of construction could be divided into two. First is the opportunity to design and construct buildings without the constraint of passive measures to maintain cool comfort. The second was the opportunity to introduce new materials and construction techniques in the knowledge that air conditioning will maintain a comfortable environment (Arnold, 1999). Hence, the effort in finding new ways of improving air conditioning application will be in parallel with the development of construction practices. In this chapter, the literature review begins with the summary of some past research on cooling system comparison. Fundamental arrangement of cooling system alternatives and heat transfer concept are then highlighted, followed by the characteristics, features and drawbacks of air conditioning systems.

2.2 Refrigeration Cycle

Refrigeration is a method of removing heat from the conditioned space. It takes four basic processes to complete the cycle of refrigeration which started with compression, condensation, throttling and evaporation. The process could be illustrated as in Figure 2.1.

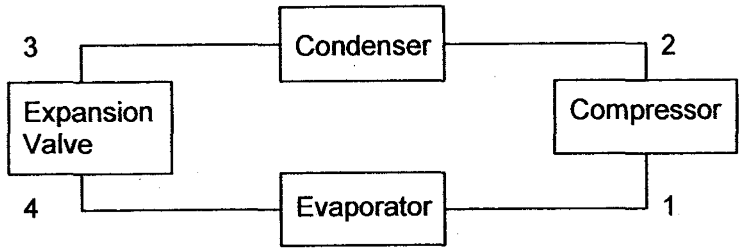

Figure 2.1: Refrigeration cycle

Process 1-2 (Compression): Refrigerant in the state of saturated vapour and low pressure, enters the compressor and being compressed to a higher pressure. For a low capacity application, a reciprocating type of compressor is normally used. Screw type compressor is suitable for medium range cooling load while centrifugal type is for high capacity demand.

Process 2-3 (Condensation): Refrigerant vapour enters the condenser at constant pressure and condenses into liquid state. Heat is released from the refrigerant to the ambient. A condenser is a kind of heat exchanger, which normally designed according to finned tube configuration. Refrigerant in the forms of superheated vapour flows through the tubes and a fan forces air between the fins and over the tubes, changing the refrigerant into sub-cooled liquid. The fan is a necessity since natural convection itself could not produce sufficient airflow and heat transfer over a condenser.

Process 3-4 (Throttling): High pressure liquid moves through expansion valve and experiences the decrease in pressure. The enthalpy is constant as the refrigerant cross the valve until it reaches the evaporator. Expansion valve also acts as the refrigerant flow controller of the system.

Process 4-1 (Evaporation): The liquid enters the evaporator and turns into saturated vapour. Therefore, heat is absorbed from the conditioned space, making it cooler and less humid. Total enthalpy change of the air is the sum of enthalpy change due to temperature drop, or sensible heat, and the enthalpy change due to condensation, or latent heat. The saturated vapour then goes back to the compressor (Sadler, 2000).

2.3 Heat Transfer Process

Heat transfer is one of the key processes in air conditioning system. The science of heat transfer is concerned with the analysis of the rate of heat transfer taking place in a system. The heat transfer cannot be measured directly, but the concept has a physical meaning because it is related to the measurable quantity called temperature. It has been long established by observations that when there is temperature difference in a system, heat flows from the region of high temperature to that of low temperature. In the study, it is necessary to consider three modes of heat transfer which are conduction, convection and radiation. Temperature distribution in a medium is controlled by the combined effects of these three modes. Therefore, it is not actually possible to isolate entirely one mode from interaction with the other modes. However, for simplicity in analysis, one can consider a particular mode of heat transfer whenever the other modes are negligible (Ozicik, 1985). For air conditioning system design, the heat transfer process is only significant in terms of conduction and radiation in the research of cooling load calculation.

2.3.1 Conduction

Conduction is the form of heat transfer which takes place when it moves through a material. It occurs due to atomic or molecular impact which results from vibration in the case of solids, or movement in the case of liquids or gasses. Solids, with more compact molecular structure, will show the greatest conductivity compared to liquids, which have molecular dispersal and gasses, which have greater molecular dispersal. The transfer of heat by conduction could be increased by increasing the area through of heat transfer, higher the temperature difference and lower the thickness of material (Joel, 1996). Fundamental theories regarding the concept of conduction can be understood by the following explanation.

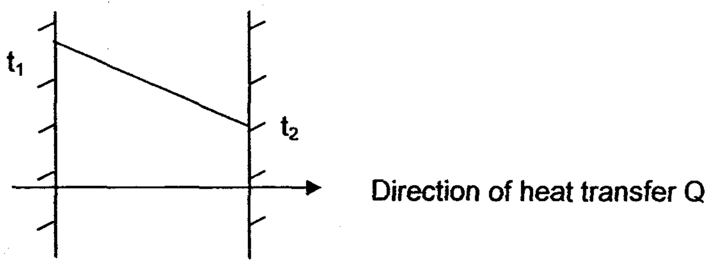

Figure 2.2: Heat transfer process

Consider a wall of thickness x and heat transfer area A as shown in Figure 2.2. The temperature of its faces is t_1 and t_2 respectively. Next, consider an elemental thin slice within the material of thickness δx. Let the temperature fall across this elemental thin slice as δt. Then

$Q \propto A\,(\delta t/\delta x)$

$= -uA\,(\delta t/\delta x)$, where u is called the heat transfer coefficient

$= -uA\,(t_2 - t_1)/x$, assuming temperature fall to be linear through thickness x

$= uA\,(t_1 - t_2)/x$ (2.1) (Joel, 1996)

This is known as Fourier's equation, where the minus sign in the equation indicates that the heat transfer occurs in the direction of decreasing temperature, an association with the second law of thermodynamics that heat will only transfer down a temperature gradient.

2.3.2 Solar Radiation

Radiation is an electromagnetic incident of varying wavelength similar to the transmission of light. Unlike conduction, radiation requires no transfer medium between the emitting and receiving surfaces. The sun transmits its energy to the earth where in radiation it is the temperature of emitting surface that controls the energy quantity rather than temperature difference in conduction. Fortunately, all of the transmitted solar radiation does not immediately act to increase the cooling load, some of it is stored in the floor and internal walls, which absorb the radiation and are warmed by it (Stephenson and Mitalas, 1963). The energy, E, transmitted by thermal radiation is proportional to the fourth power of the absolute temperature, T. Therefore $E \propto T^4$

$$Q = \sigma T^4 A, \text{ where } Q \text{ is the energy rate} \qquad (2.2)$$

σ is Stefan's constant = 5.6697×10^{-8} W/m^{2}K^4

A is the surface area (Joel, 1996)

This is known as Stefan-Boltzmann's equation. For a glass-enveloped building, solar radiation gives more impact to the cooling load. As stated by Stephenson and Mitalas (1963), for modern multi storey office building with 80% of the exterior wall made of glass, maximum cooling load of solar radiation has been found to be about 60% of the maximum instantaneous heat gain.

2.4 Cooling Load

Air-conditioning load calculation is the design load estimation for an air-conditioning system. Based on design requirement and thermal properties of the building, cooling load of the building will be estimated to determine the design flow rate and capacity of the air-conditioning system and its equipment. In its simplest term air conditioning load can be divided into heating load and cooling load. The calculation of heating load is usually more straightforward because the heat transfer in a room in winter is relatively stable. In the coldest weather period the room may not receive sunshine, therefore, the heat gains from the sun, occupancies, lighting and equipment are usually not considered in the estimation of peak heating load. Thus, a steady-state calculation method is usually enough for computing heating load. However, for cooling load calculation, the complex effect of heat transfer, solar radiation and heat storage has to be considered and this makes the calculation complicated (Hui and Cheng, 1998). Therefore, extra attention must be taken in determining cooling load where experience is vital in making judgements and assumptions. In addition, heating loads are purely based on thermal energy transfer driven by temperature difference, while cooling loads are made up of two distinct components which are sensible and latent heat (Chasar, 2004).

Cooling load is best determined by manual calculation or software computation. However, as mentioned by Vieira (1996), many contractors rely on the inaccurate quick estimation method based on the floor area of the house, where normally one tons of cooling capacity is provided for 500 ft^2 of house. Building designers are often limited by time and resources, and they usually can only use simple and quick method for analysing and solving the design problems. During the outline design stage, because the building design may often change and the building structure and materials may still not decided, designers can only use rough calculation method for their analysis (Hui and Cheng, 1998).