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ABSTRACT

This research was aimed to control thermal environment (temperature and relative humidity) in air-conditioned rooms in order to reach thermal comfort and good health for the people in hospital. This research was divided into 2 sections: Section 1 studies the direct and indirect influence of relative humidity on the health of people inside hospital buildings and the appropriate relative humidity and temperature to achieve thermal comfort and good health for Thailand by using Delphi technique; Section 2 develops single phase air conditioning system using inverter to control thermal environment (temperature and relative humidity) inside the room to reach the appropriate temperature and relative humidity. The results in Section 1 showed that too high and too low relative humidity had direct and indirect effects on sick building syndrome (SBS), illness, respiratory diseases, growth and distribution of bacteria, virus, and house dust mite. The appropriate temperature and relative humidity for Thailand were 26 degrees Celsius and 50-60%, respectively. The results in Section 2 showed that the developed system could control temperature and relative humidity at the desired level with the changes in temperature and relative humidity in the range of $\pm$0.35 degrees Celsius and 50-60%, respectively. The development of industrial technology for single phase air-conditioner which can control temperature and relative humidity at a steady level using inverter will lead to good quality of life for the people in hospital in a sustainable manner.

Keyword: Temperature and Humidity Control; Inverter; Delphi technique; Healthy; Thermal comfort.

INTRODUCTION

Thermal comfort is a reaction which humans can feel concerning heat and cold (D Holm 2005). A room with thermal comfort means a room where 80% of all persons inside could accept the environment (ANSI/ASHRAE Standard 62-2001). Thermal environment affects human comfort due to location and weather (Ruey-Lung Hwanga 2007). The design of buildings and offices must depend on human comfort (M. Kavgic 2008), especially in hospital buildings where there are patients, staff members and other relevant persons under the risk of infection through germs, bacteria, virus and the like. The control of appropriate thermal environment, therefore, is important for thermal comfort and good health for the persons in hospital (Ruey-Lung Hwanga 2007).

The general public understood that good control of thermal environment was only to control temperature inside the room but there were still a lot of people inside such environment suffering from nose irritations, stuffed nose, rainy nose, eye irritations, cough, tightness in the chest, fatigue, headache and skin irritations. Such symptoms are called sick building syndrome (SBS) which is affected by relative humidity inside the room (Arundel, A.V 1986) because humidity affects the rate of water evaporation in the air and the balance of energy inside the body and thermal comfort of human beings (L. Harriman 2001).

Medical studies from foreign countries have shown that it is important to control humidity in hospital buildings and the law is enacted. In Thailand, however, there has been no such action and the research on the influence of relative humidity on thermal comfort and good health of human beings is scarce. At present, air-conditioning systems used in most houses and offices is split type air-conditioner which cannot control temperature and relative humidity at a stable level. Inverter air-conditioners can only control temperature at a stable level; it cannot control relative humidity at a stable level. Therefore, a device to increase or reduce humidity is needed and costs a lot of money. Moreover, it cannot control relative humidity at a stable level in the desired range. Therefore, the researchers decided to study the direct and indirect effects of relative humidity on the health of the persons in hospital buildings in Thailand. The results would be used to design and develop a single phase air-conditioning system which could control both temperature and relative humidity at a stable level in a short time with the temperature changes in the range of $\pm$ 0.5 degree Celsius and relative humidity changes in the range of 50-60%. There would be genius control system for air-conditioners using an inverter to control the growth, distribution and existence of germs, bacteria, virus, house dust mite and fungi. This would bring sustainable good health and thermal comfort for the persons in hospital buildings.

Influence of Humidity on Thermal Comfort and Good Health of Human

Case studies and research on epidemiology suggest that relative humidity has a direct effect on cell membranes which is related to respiration, contraction, nose tissue inflammations or influenza and fever. It also has an indirect effect on the growth of allergies and respiratory diseases along with the existence of diseases like fungi (e.g., *Aspergillusfumigatus)*, protozoa, house dust mite, bacteria (e.g., *Streptococcus, Legionella)* and virus (e.g., common cold, flu) (Baughman_ Edward A 1996) (as shown in Figure 1). Relative humidity also affects the intensity of chemical pollution in the air by changing the distribution rate of gas from the materials used inside the buildings and the reaction between water and chemicals in the air (Arundel, A.V 1986).

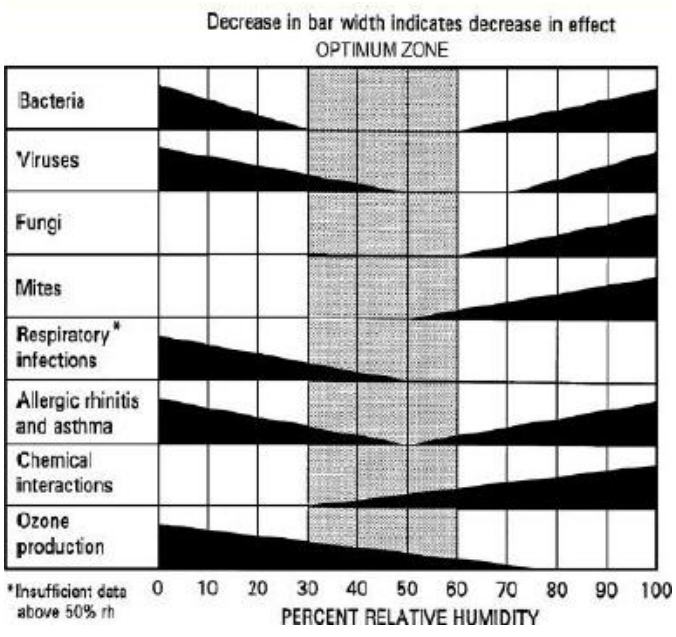

Figure 1: Optimum relative humidity range for minimizing adverse health effects.

Relative humidity has a direct effect on cell membranes which is related to respiration, contraction, nose tissue inflammations or influenza and fever. Recent studies have shown that the increase in humidity can reduce the nose tissue inflammations. It was found that the increase in humidity can reduce the nose irritations of 4 people out of 22 people in the sampling group (Hashiguchi, N 2007).

As for 22 participants in the test, relative humidity might have an effect on nasal mucus in the respiratory canal. Stuffed nose can cause respiratory problems in the mouth. A study in the effect of relative humidity on the viscidity of the nasal mucus has shown that the viscidity reduces doubly when the relative humidity is 100% or 60%. The vapours from the increase in humidity-both accidentally and willingly-might be useful because the vapours can reduce the viscidity of the nasal mucus and reduce the growing rate of germs in respiratory system, cough and nose tissue irritations in children with respiratory problems (Arundel, A.V 1986).

Hemmers et al. reported that an environment with relative humidity lower than 50% will increase the spreading rate of influenza virus. Low humidity is also related to a tissue weakness (Hemmers, J.H. 1960). Hiraga installed an ultrasonic device to increase the humidity in 222 houses. The results were that an appropriate increase in humidity is useful to reduce various diseases and respiratory diseases (Hiraga, Y1981). Tsutsumi et al. tested the effect of low humidity on comfort and other results in participants under stable circumstances in summer (Tsutsumi H 2002). Ibamoto et al. reported that low humidity was possible for thermal comfort in both transient and steady state (Ibamoto .T 2001).

Air-Conditioning System

The design and installation of air-conditioning systems to control thermal environment to achieve thermal comfort inside hospital buildings should comply with the ASHRAE Standard 55 which is the most appropriate (ASHRAE Standard 55-2004). Comfortable thermal environment in hospital can make the patients and staff members feel good and better (Ruey-Lung Hwanga 2007). The control of relative humidity as in ASHRAE 2001 (item 8.12) reads that relative humidity to achieve thermal comfort should not exceed 60% (ASHRAE Handbook: Fundamentals 2001).

Most buildings were installed with air-conditioning systems to build up good environment for the persons inside. There were two control systems according to the factors: System 1 controlled only comfortable air conditioning; System 2 controlled both relative humidity and precision air conditioning (Long Enshen 2005). Both systems were intended differently in that air-conditioners with System 1 were used to create good environment by controlling only temperature. They could be an inverter or normal device. Air-conditioners with System 2 were used to maintain the stability of electronics and computer only. They were not intended for household because they cost 5 times more. The smallest size was 48,000 BTU. They occupied more area than System 1 and they could not control the speed of the compressor motor. They also wasted electricity power since it added vapours inside the room.

RESEARCH METHODOLOGY

This research was divided into two sections: Section 1 studies the direct and indirect influence of relative humidity on the health of people inside hospital buildings and the appropriate relative humidity and temperature to achieve thermal comfort and good health for Thailand by using Delphi technique; Section 2 develops single phase air conditioning systems using inverter to control thermal environment (temperature and relative humidity) inside the room to reach the appropriate temperature and relative humidity with precision.

Section 1: The Delphi technique

The Delphi technique used in this study was to brainstorm the ideas from the experts in 3 following topics:

1. The influence of humidity on the growth of diseases of people living in air-conditioned rooms in both direct and indirect ways such as influenza, respiratory diseases, asthma, tuberculosis, eye irritations and allergies.
2. The relationship between relative humidity and the growth as well as the distribution of bacteria, virus, fungi and other pathogens which affect the health of human beings in both direct and indirect ways.
3. Optimal relative humidity and temperature to give thermal comfort and good health of human beings in Thailand

Procedure was as follows:

1. A group of 11 experts was chosen using purposive sampling method from the Faculty of Medicine and the Faculty of Tropical Science, Mahidol University.
2. The tools to collect the data from the experts were developed for 3 times. They were an interview form and a questionnaire.
3. The data was analysed in a statistical manner to find out the consistency and the probability in 5 scales for the questions

Section 2: Temperature and Relative Humidity Control System

Details and how the system works

The main components of temperature and relative humidity control system by split type inverter air-conditioning system with inverter installed to control the speed of compressor motor (1 phase type), ultrasonic humidifier, electric heater and control unit (as shown in Figure 2).

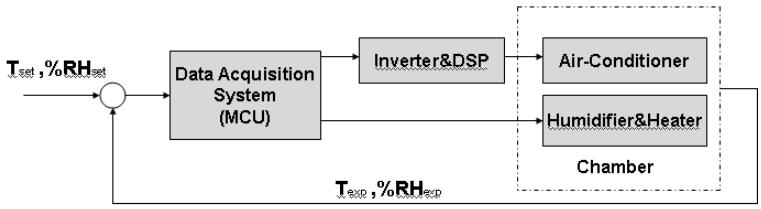

Figure 2: System control algorithm block diagram

The system works as follows: Data acquisition system (MCU) detects the temperature and relative humidity in the test room ($T_{exp,}\%RH_{exp}$) and compare them with the default or set value ($T_{set,}\%RH_{set}$). If the temperature is higher than the set value, MCU will send the data to DSP (Digital Signal Processing) to increase the speed of compressor motor to increase the flow rate of refrigerant . When the temperature becomes as set, the speed of the compressor motor will be decreased as appropriate which is decided by fuzzy logic program. In case that relative humidity is lower than the set value, MCU will tell ultrasonic humidifier to increase the amount of vapour in the test room. If the relative humidity is higher than the set value, the humidity in the room must be decreased. In this case where the humidity is reduced, the temperature in the room will become lower as well. MCU will tell electric heater to increase the temperature in the room. Therefore, such system can control the temperature and relative humidity in the desired range as always.

Experiment and Materials

In this experiment, the room was the bedroom of 20 square meters with single phase split type air-conditioner (18000 BTU), ultrasonic humidifier (200 millilitres per hour), electric heater (2 kilowatts) and inverter to control the speed of compressor (Figure 3). The temperature and relative humidity are detected by STH15. The data were recorded by Hioki datalogger at every 5 second for 8 hours from 10 pm to 6 am. The experiment was divided into 2 cases: Case 1 (Figure 3) used inverter to control the speed of compressor motor of air-conditioner and it had ultrasonic humidifier along with electric heater to control both temperature and relative humidity. The temperature and relative humidity were set at 28.5 degrees Celsius and 50-60% respectively. Case 2 (Figure 4) used thermostat to control compressor of the air-conditioner without relative humidity control system. The temperature was set at 26 degrees Celsius. The data concerning temperature and relative humidity in the room was recorded as done in Case 1. During the experiment, the data concerning temperature and relative humidity outside the room was also recorded from 6 am every 2 minutes for 24 hours. There were 703 records (Figure 5). After considering temperature and relative humidity in Figure 5, we found that during night time relative humidity reached 80% whereas during day time relative humidity was about 45% which was quite low. This indicated that Thailand has high relative humidity.

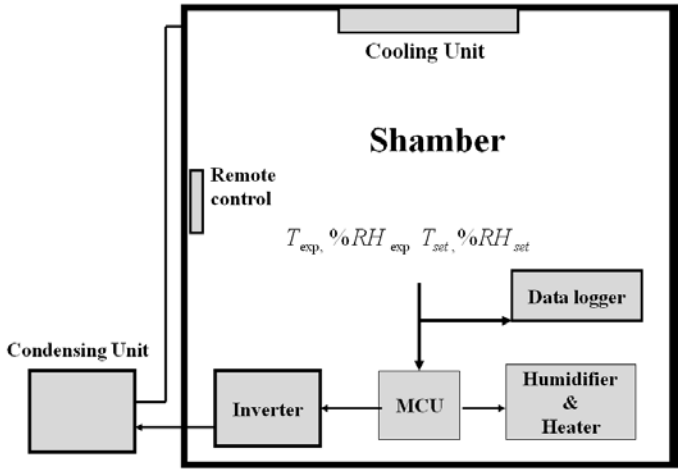

Figure 3: Schematic diagram of the experimental setup : case 1

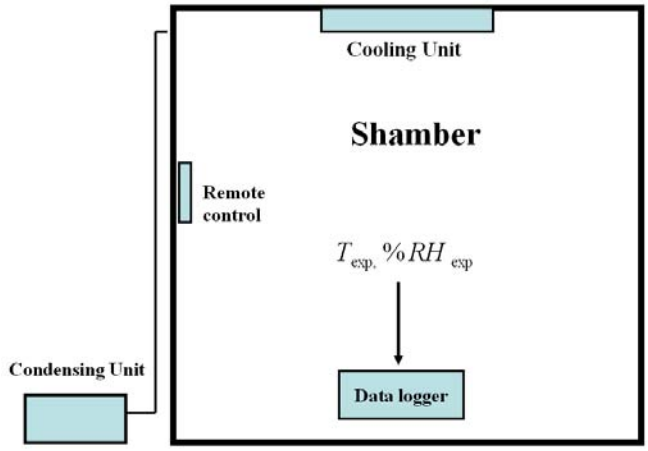

Figure 4: Schematic diagram of the experimental setup:case 2

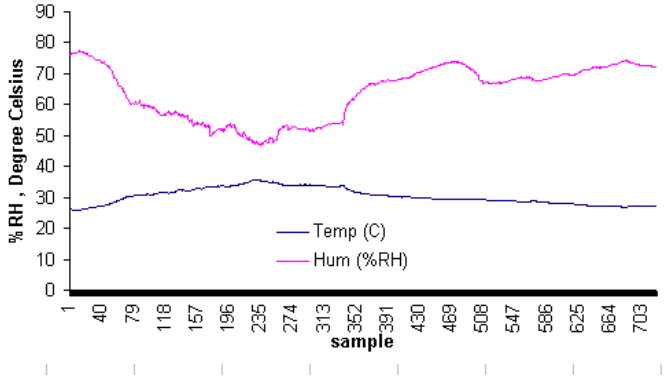

Figure 5: Temperature and Relative Humidity outside the Room for 24 Hours

RESULTS AND DISCUSSION

Delphi Technique

As for the study of relative humidity which affect the health of people living in the hospital buildings in Thailand, the questions which the experts agreed with and showed the probability at the most level were as follows: 1) Thailand is tropical; therefore, there are diversity in tropical medicine; 2) Humidity in the air influences the growth of bacteria, virus, house dust mite and fungi; 3) Relative humidity has an indirect influence on diseases, rhinitis and allergies; 4) The value of relative humidity and temperature in the range of comfort zone by ASHRAE can be applied in Thailand; 5) The influence of relative humidity on bacteria, virus, fungi and house dust mite, according to ASHRAE, can be applied in Thailand; 6) The control in relative humidity in the range of comfort zone will give good results to the health and the comfort of people living in air-conditioned rooms; 7) Rooms whose relative humidity and temperature are controlled are to keep the sustainability of the medical devices and equipment only; 8) Air-conditioned rooms which can precisely control the temperature and relative humidity will give better results to the health and comfort than traditional air-conditioned rooms. All questions had the same value for the median, that is 5.

Temperature and Relative Humidity Control System

Results from the experiment on working with temperature and relative humidity control by inverter air-conditioner (Case 1) and normal air-conditioning system without inverter and humidifier (Case 2) in the same environment for 8 hours were as follow: In Case 1, there were 5670 records of temperature and relative humidity data (Fig.6).

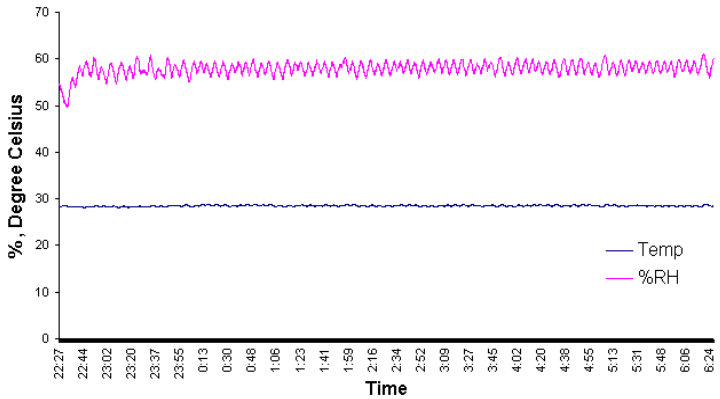

Figure 6: Results from Case 1

It was found that the highest temperature was 28.8 degrees Celsius. The lowest one was 28.1 degrees Celsius. The highest relative humidity was 59.8% and the lowest one was 50%. The results from Case 2 were as follows:

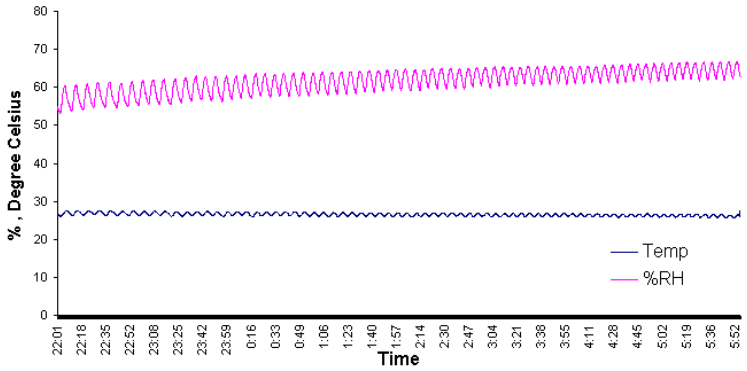

Figure 7: Results from Case 2

There were 5706 records of temperature and relative humidity (figure 7). It was found that the highest temperature was 27.6 degrees Celsius and the lowest one was 25.6 degrees Celsius. The highest relative humidity was 66.8% and the lowest one was 53.2%.

According to the results of 2 experiments, it was found that in case of temperature and relative humidity control, the changes were in the range of ±0.35 degree Celsius and the relative humidity was between 50-60% as a desired condition. As for Case 2, there was only temperature control and no relative humidity control. It was found that the changes in temperature were higher than set around 1.6 degree Celsius and the relative humidity was quite high or 50-60%. According to Figure 7, it could be found that as time passed, the relative humidity inside the room became higher and higher although water got condense all the time. This was because relative humidity from outside could get inside the room. During night time, high relative humidity caused air-conditioner to use more energy to drive out a large amount of water. According to both cases, Case 1 could control environment as a desired condition.

Due to the fact that this experiment was done inside the bedroom where there could be changes in heat all the time through heaters inside the room, human activities along with opening-closing door, there were changes in heat and humidity all the time. Relative humidity outside the room was another factor which was essential for the experiment because there was a leak in the room, allowing relative humidity outside the room to get inside. The relative humidity inside the room was higher then. Therefore, Case 2 in which there was no relative humidity control showed higher changes in temperature and relative humidity than Case 1.

CONCLUSIONS

Delphi technique results showed that the experts agreed on the fact that relative humidity affects thermal comfort and health of human beings. Therefore, in air-conditioned rooms, there should be temperature and relative humidity control system to achieve thermal comfort and good health for the persons inside the room, especially in hospital buildings because it is good for patients and staff members.

Temperature and relative humidity control system using inverter air-conditioning system in this research could control temperature and relative humidity in the room as a desired condition. The changes were different from the set value around ±0.35 degrees Celsius and it could control relative

humidity between 50-60% which was the appropriate range for Thai climate. If the system is used in the buildings which need to control thermal environment such as hospitals, patient's rooms, houses or offices, there will be thermal comfort and good health for the people living inside.

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