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INDOOR CLIMATE CHAMBER DESIGN AND PERFORMANCE

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ABSTRACT

Indoor climate studies have resulted in building codes which give a positive input to the lives of people. However, knowledge about particular problems in hot and humid tropical climates is still limited. Developing countries in hot and humid regions face particular restraints in the adoption of many technical solutions to indoor climate problems. The installation and running costs of many solutions known from developed countries may be prohibitive.

The Indoor Climate Laboratory is UP Mechanical Engineering's response to this need for a better quality indoor environment in tropical climates especially when resources are limited. Three climate chambers have been built and their performances are reported in this paper.

INTRODUCTION

Majority of indoor climate researches have been done for countries in the temperate region and most of them are rich countries belonging to the First World. As such, the results of these researches may not be applicable to countries in the tropical regions whose outdoor weather conditions and resources are very different from the former.

Indoor climate research in the hot and humid tropical climate of the Philippines has just been recently started. Heat, noise and dust are often felt indoors and outdoors. There has been very little money to support local research on indoor climate. Thus, legislation and building designs are based on codes and regulations intended for developed countries in temperate regions. They are not based on local formal scientific studies and may not be applicable to local conditions.

Presidential decree 1096 (1977), known as the Philippine Building Code, gives some minimum requirements for mechanical ventilation. It requires that when mechanical ventilation is installed, the air change rate must be at least 3 air changes per hour for offices. It also states that temperatures of 68-74°F (20-23°C) are considered comfortable.

Although the general requirements of the Philippine Building Code are comparable to other building codes, it is not clear about the requirements for recirculation, the requirements for natural ventilation or when a room is considered to be mechanically ventilated. It is for example unclear whether a window-mounted recirculating air conditioner is considered mechanical ventilation. Also, the room temperature range (20-23°C) that is considered comfortable as stated, is too cold for Filipinos in their usual office attire. (1)

More knowledge about warm environments has been generated from a previous research conducted at the Indoor Climate Laboratory entitled "Low cost personal cooling in hot humid offices" (2). The combined effect of temperature and humidity has been investigated in a comprehensive study with heat acclimatized human subjects. The project has established a relation between acceptability of the environment, supply air humidity and temperatures for conditions that are warmer than comfortable.

Clausen, et al. Have tried to established equally comfortable environments by varying either noise, temperature or air quality. Their experiments were however performed with only one parameter at a reduced level at a time. The study undertaken at the U.P. Indoor Climate Laboratory involved three parameters, each of which has a realistic link with temperature.

The sensation of draft created by air velocities in the range of 0.05 m/s to 0.5 m/s has been studied by Fanger et al. (3). The study resulted in maximum air velocities for comfort at comfortable temperatures. In warm environments, fans are in widespread use for the reduction of heat stress. Little knowledge exists on the effect of high temperatures on preferred air velocities.

As the following examples indicate, temperature is often linked with the parameters for air velocity, noise and daylight.

1. A fan is a well known means of reducing heat stress in a warm environment. The reduced heat stress makes it pleasant to have some air movement. (4) There is no scientific background to predict preferred air velocities at elevated temperatures.

2. Some air conditioners are too noisy when turned on. A noisy air conditioning unit will reduce the occupant's willingness to have a higher room temperature. At present, makers of air conditioners do not take into account the trade-off between cooling capability and noise generation due to lack of scientific data based on user's preferences.

3. In a warm climate, daylight may be reduced or windows completely removed to avoid the heat contribution from solar radiation. Sky luminance and artificial lighting are not the main factors which govern the choice of window size but rather the effect of visual contact with the outside which relieves the sense of being enclosed. (5) It may therefore be more acceptable to allow the temperature to increase and still have the daylight and visual contact with the surroundings.

These examples indicate everyday optimization tasks in warm environments involving the trade-off between two parameters. Often, decisions on the balancing of the two parameters are made by building designers. Because there has been no scientific study to date for this balancing of parameters, the risk is that the balance point may not be in agreement with the wishes of building users. There is an obvious need for empirical verification of the trade-off between parameters.

CLIMATE CHAMBERS AND AIR PROCESSING SYSTEM

A. CLIMATE CHAMBERS

Three single-person climate chambers have been designed, built and tested for the purpose of making optimization studies of the indoor climate. Figure 1 shows schematically the three chambers and duct system, as well as the locations of the temperature and relative humidity sensors which are indicated by encircled "t" and "RH" respectively. Figure 2 is a photograph of the setup.

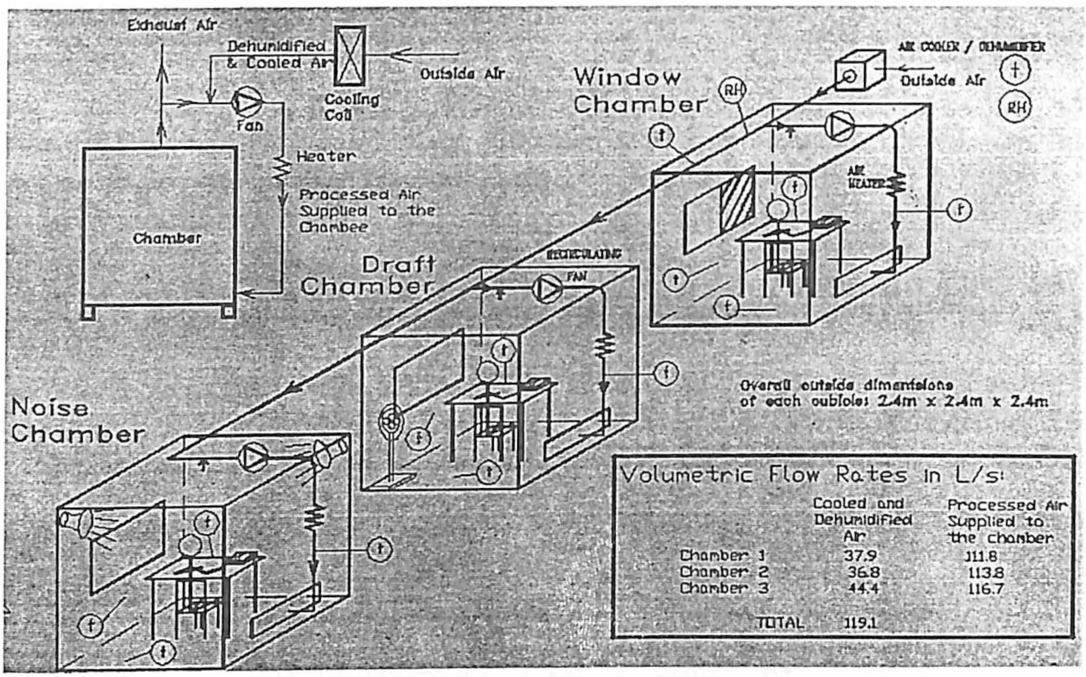

Figure 1. System schematic diagram showing the three climate chambers, ductwork, and location of temperature and humidity sensors.

The walls, floors and ceilings are of double-sided construction with insulation. The overall heat transfer coefficient (U-factor) of the walls is 1.106 W/m^{2}K for the floors and ceilings. The chamber air temperature can be controlled by the subject over a range of 22 °C to 33°C.

In the draft chamber, air velocity is generated by a traditional stand fan located diagonally behind the subject. The draft reaching the seated subject can be varied from less than 0.1 m/s to a maximum of 1.2 m/s by varying the input voltage to the fan.

Noise is generated in the noise chamber by playing back a pre-recorded tape of noise from a window-type air-conditioner. The noise level can be varied from a background noise level of 56 dB_A to as high as 90 dB_A using the volume control knob of the audio playback equipment.

The window opening of the third chamber can be adjusted by a sliding door on the outer side of the window. The positions of the sliding door marked at equal distances from the fully closed to the fully open positions.

Each chamber has a 0.94 m^2 doubled-glazed glass window on the left side of the seated subject without direct sunshine. The door is located behind the seated subject and has a small glass window. The chamber interiors are painted white, the tables are painted gray, and the chairs are varnished. Supplementary lighting comes from two 40-watt incandescent bulbs.

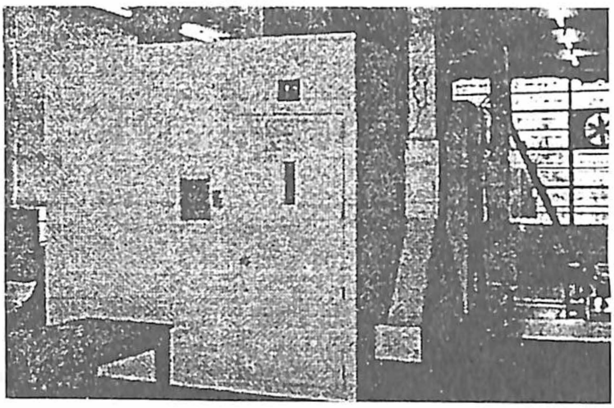

Figure 2. Photo of climate chambers

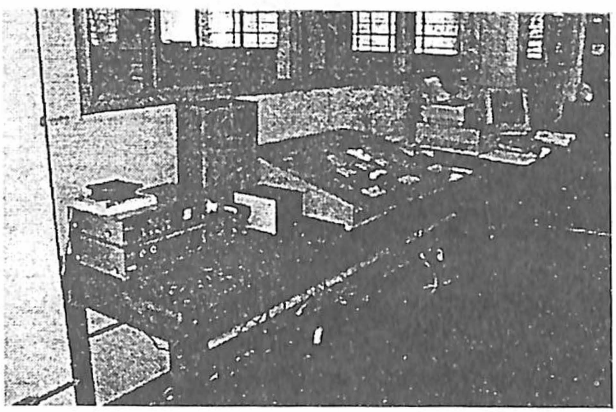

Figure 3. Data logger, PC and other instruments and control devices.

B. AIR PROCESSING SYSTEM

Outside air goes through the cooling coil of a window air-conditioning unit where it is cooled and dehumidified before it is distributed more or less equally to the chambers by a duct system shown in Figure 1. This cold/dehumidiefied air mixes with the return air that is extracted from the top of the chamber. A constant speed blower moves this mixture to an electric heater where it may be heated as needed before entering the chamber through a 1.5m x 0.2m grilled velocity diffuser on the right side of the seated subject 0.15m above the chamber floor. The room temperature is set by an automatic temperature controller which controls the electric power input to the heater. An average air velocity of 0.1 m/s reaches the seated subject as measured by a hot wire anemometer from Bruel and Kjaer of Sweden.

Temperature sensors are installed at various points in the duct system, outside and inside the chambers. Copper constantan thermocouples and individually adjusted CRAFTEMP thermistors from Astra Tech AB of Sweden are used as temperature sensors. Two OMEGA HX92 relative humidity transmitters, made by Omega Engineering Inc., USA are used to monitor the relative humidity of outdoor air and the dehumidified air. Data readings are logged automatically by a DATATAKER DT100 made by Data Electronics Pty. Ltd., Australia, which in turn is interfaced with a personal computer. Figure 3 shows the DATATAKER, personal computer, and other instruments and control devices used in the set up.

METHODS

A. CALIBRATION

Calibration of the temperature and relative humidity probes was done by subjecting them to two different conditions: The temperature probes were put in a box where the temperature was measured by a psychrometer with quick silver thermometers (± 0.2°C) and then in a pot of boiling water. The relative humidity sensors were put in a box in the laboratory and then in the hot and dry airstream leaving an absorber dehumidifier that was set up for this purpose. The psychrometer was placed beside the relative humidity sensors in each case and the relative humidity was obtained from psychrometric chart. A linear relationship was assumed for both the temperature and humidity sensors.

In the draft chamber, the functional relationship between voltage applied to the stand fan and the average air velocity at the seated subject was determined by using Turbometer, a vane-type anemometer from Davis Instruments, Hayward, CA, USA. This was done to facilitate the determination of draft velocity by simply reading the voltage supplied to the fan. Thus, for the test runs, voltages supplied to the fan were read or set instead of draft velocities.

In the noise chamber, the volume control knob setting of the audio cassette player was calibrated against the chamber noise level using a Testo 815 sound level meter from Testo Gmb H&Co., Lenzkrch, Germany. This functional relationship facilitated the use of volume control knob setting as raw data taken during the test runs rather than noise level readings.

In the variable window opening chamber, a Mavolux digital light meter made by Gossen in Germany was used to determine the wattage of supplementary lighting needed to ensure an acceptable illumination instensity reaching the surface of the table when the window is in the fully closed position.

B. TEST RUNS

Air flow rates through the ducts were determined using the average of the velocities measured by a pitot tube at nine points (3 x 3) across a duct section.

The dry-bulb temperatures and relative humidities of the air entering and leaving the cooling coil were obtained, together with the volume flow rate.

The response of the temperature probes to a step change in temperature was done by taking the air temperature reading when the probe was in the coldest portion of the duct and then suddenly withdrawing and exposing it to the ambient temperature.

To determine how much time it takes to raise the chamber air temperature from 23°C to a preset temperature reading when the probe was in the coldest portion of the duct and then suddenly withdrawing and exposing it to the ambient temperature.

Similarly, to determine how much time it takes to cool the chamber air, its temperature was initially set at 33°C and when the temperature had reached a constant value, the heater was completely turned off until it reach a constant low temperature of 24 °C.

Finally, to see the effect of the sudden increase in internal heat load on the room temperature, the chamber air temperature was set at 25°C. When the room temperature had assumed the set value, several lamps with a total wattage of 500W were turned on to provide the desired sudden increase in internal heat load. The room air temperature readings were taken until the temperature had leveled down to the original temperature of 25 °C.

RESULTS AND DISCUSSION

Volume flow rates of air supplied to the chambers from the cooling coil are 37.9, 36.8, and 44.4 L/s respectively for Chambers 1, 2, and 3. A total of 119.1 L/s is cooled and dehumidified from 29°C DB and 67%RH to 14°C and 97%RH by the window air-conditioning unit. The volume flow rates of air recirculated through the chamber by the blowers are 111.8, 113.8 and 116.7 respectively (See Figure 1).

The thermocouple response curve is shown in Figure 4. It took 80 seconds for the reading to reach the final temperature of 32 °C from an initial temperature of 13°C or an overall average rate of about 14.25 °C/min. However, for the temperature rise or an overall average rate of 28.5°C/min. This attributed to the fact that the temperature rise took place in still air (practically no velocity), while during the temperature drop, the air velocity over the sensor was about 9 m/s inside the duct where the 13°C air was flowing resulting in a much larger convection heat transfer coefficient. Note that for either case, the rate of temperature change is high at the start, slowing down as time passes by. Thus, for either case, it only takes about half of the total time to reach 90% of the total step change. The response time for the temperature probes are quite fast, taking only a few seconds to reach the correct reading.

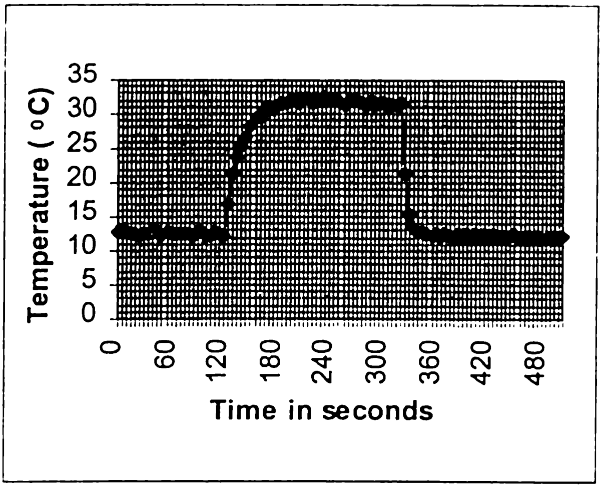

Figure 4. Thermocouple response curve.

Figure 5 shows the room temperature would rise when the thermostat setting is suddenly increased from 23°C to 33°C. The individual responses of the three chambers were *quite similar*. Chamber 3 had the best or fastest response. This was due to the fact that its recirculated air flow rate was slightly higher that the two others. It took a total of 90 minutes for the room air temperature to reach 33 °C from 23°C. Although the overall average of the temperature rise was about 0.11°C/min, the rate at 24°C was 0.40°C/min, going down to 0.30°C/min at 26°C; 0.21°C at 28°C/min and 0.14°C/min at 30°C. In short, the response time decreased with increasing air temperature.

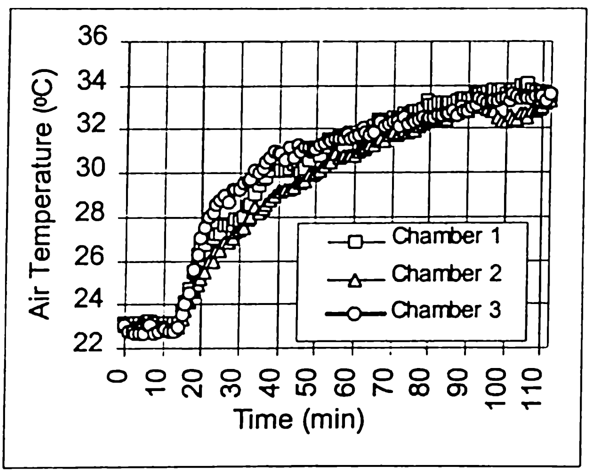

Figure 5. Chamber air temperature response due to a sudden step increase in thermostat setting from 23°C to 33°C .

For the chamber air temperature response due to a sudden step decrease from 33°C to 24°C, the change took about 80 seconds, giving an overall average of about 0.11°C/min which was the same as in the previous case. Likewise, chamber 3 showed a slightly better response time than the other two. Again, this was due to its higher recirculating air flow rate and a higher cold/dehumidified air flow rate drawn into this chamber. The rate of temperature drop at 32°C was 0.70°C/min; going down to 0.58°C/min at 30°C; 0.23°C/min at 28°C and a very low rate of 0.07°C/min at 26°C. Like in the preceding case, the response time was very good at the start (high temperature) and slowed down at the lower temperatures.

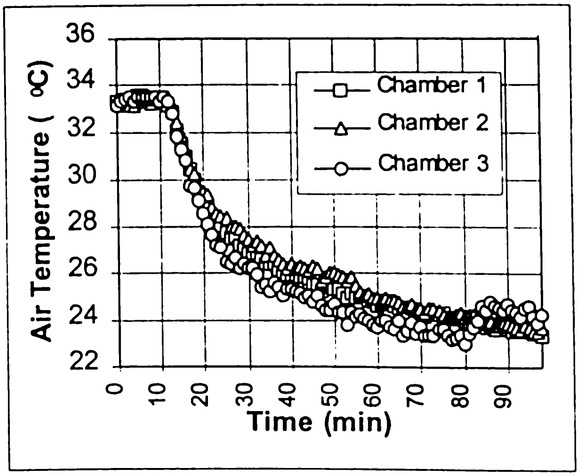

Figure 6. Chamber air temperature response due to a sudden step decrease in thermostat setting from 33°C to 24°C .

With regards to the effect of a sudden increase in the internal heat load on chamber air temperature, Figure 7 shows how the room air temperature responded as a function of time. The room temperature slowly rose by only 1.0°C in about 35 minutes before going down to the original temperature of 25°C in another 30 minutes. The additional heat load of 500W from several incandescent lamps was at about the same order of magnitude as the room total heat gain which was estimated to be 460W. Thus, by turning on all those lamps, the room total heat gain had practically more than doubled from 460W to 960W.

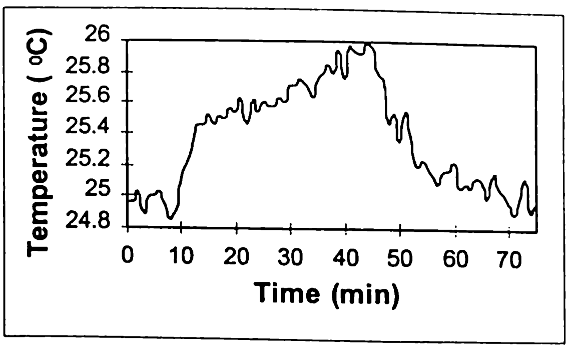

Figure 7. Chamber air temperature response due to a sudden increase in internal heat load of 500W.

CONCLUSION

The three chambers performed as expected and they can be used in experiments requiring a wide range of room air temperature regardless of outdoor air conditions. The room can be maintained at a temperature ranging from as low as 22°C to as high as 35°C. The air temperature response to a change in thermostat setting is adequate for most steady-state experiments. However, faster response can easily be achieved by increasing the heater heating capacity and/or replacing the window air conditioning unit with a larger one. If an experiment or study requires control of relative humidity, an air humidifier could be added as needed.

The complete setup is equipped with instrumentation and data logging capabilities. Including the use of a PC for storing and processing the data. Experiments involving trade-off effects some parameters, such as noise, draft, and window opening versus temperature have been performed in this laboratory. (1)

Information about the trade-off effects becomes increasingly important in a developing country with limited resources for optimizing all parameters in the indoor environment. Continuing research activities in these and related areas can do much to improved the quality of the indoor environment as they become the basis for updating local regulating codes.

ACKNOWLEDGMENT

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