THE ANALYSIS OF ENTHALPY CONTROL STRATEGIES AND ITS APPLICATION IN HOT AND HUMID CLIMATES

by

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ABSTRACT

Air enthalpy control strategy, or often known as free cooling, has been very effective in conserving building air-conditioning power consumptions -in moderate climatic areas. However, it stands for a challenge on its application in hot and humid areas, such as in Taiwan, where outdoor air enthalpies are constantly high.

Three control schemes, namely, those using temperature control (economizer, or T-control), enthalpy control (H-control), and the Modified temperature control (MTcontrol) were studied in this paper.

The MT-control method was actually applied on a full-scale energy test house for experimental investigation. Night ventilation in scavenging residual heat gain through building envelope had successfully introduced lower indoor temperature as expected in a typical April day.

The simulation result of their annual performances was also validated that enthalpy control strategies have quite limitted application potential in hot and humid areas, especially in the summer when cooling is most needed.

INTRODUCTION

Enthalpy control strategy has been very effective in conserving building energy on air-conditioning systems in moderate climatic areas. However, in hot and humid areas, for example, in Taiwan, the outdoor dry bulb temperature stays within a high 35 - 25 C (95 - 75 F) range most of the time and a nearly constant relative humidity of over 85% all year round. In other words, the outdoor air, with average enthalpy staying over 89 kj/kg (48 Btu/lb) in summer months while cooling are most needed, imposes heavy air-conditioning load in buildings.

On the other hand, the heavy brick wall construction in Taiwan area, which causes a 5-hour time lag of the peak heat gain through envelopes due to its thermal mass effect (1), also provides application potential for night ventilation and warrants further research efforts in investigating its feasibility. The 5-hour time lag of building envelopes in this area, makes the peak heat gain through walls occurs at around 8 pm when people already leave their offices and the building is unoccupied.

Since the thermal mass of building envelopes only "postpones" the heat conduction but does not reduce its total heat gain, so the residual heat gain still imposes load on the air-conditioning system for the next morning. Normal practice in dealing with this problem is by starting the air-conditioning plant one or two hours earlier, so that a precooling effect can be introduced, and their early peak load was cut. However, the night ventilation, which utilizes fan power only in scavenging the building residual heat, provides a better opportunity for energy savings.

The methodologies in introducing outdoor air can be classified into three catagories; namely, the economizer using temperature control (T-control) sensor, or the enthalpy control sensor (H-control) and the modified temperature control sensor (MT-control). These three design strategies are discussed in detail as the following.

T-CONTROL and H-CONTROL STRATEGIES

The T-control strategy, or commonly known as the economizer, is by drawing-in the cooler outdoor air whenever outdoor air temperature is lower than the room temperature, as shown in figure 1 region I-A and I-B. However, it can be seen that, air at region I-A which contains higher enthalpy values than the room air was also drawn in and imposes even more air-conditioning load. Furthermore, air at region II-A, which had lower enthalpy values, were not utilized because of its temperature being higher than the room temperature. This handicap leads to its replacement with the enthalpy sensor, which is the well-known H-control strategy.

In other words, as far as building energy is concerned, H-control functions better than the T-control, at the cost of more expensive and complicated enthalpy sensor, which necessitates simultaneous measurement of dry bulb temperature and relative humidity or dry bulb and wet bulb temperatures. Various enthalpy controllers are commercially available.

MODIFIED T (MT) -CONTROL

A compromising temperature control strategy as proposed by Shavit seems very promising. It essentially utilizes the common economizer temperature sensor, set at a pre-calculated threshold temperature instead of the real room temperature, and performs free cooling control strategy almost as well as the enthalpy controller with deviation of about 5% only (2).

The methodology is by first compiling the hourly bins of local outdoor temperature and average humidity ratios, and plotted on a psychrometric chart. The intersection of this outdoor condition curve with the constant room air enthalpy line then pin points the set-point of the economizer to be used, as shown in figure 2.

SIMULATION RESULTS

The Typical Meteorological Year, or often called TMY, of Kaohsiung City, Taiwan was compiled first. The TMY of Kaohsiung takes ten years of hourly weather data issued by the Weather Bureau of Taiwan, including outdoor dry bulb temperature, relative humidity, direct and diffuse solar intensities. These raw data were processed using a statistical method on a main-frame computer so that a "combined year" in representing the local long term weather conditions was obtained.

The outdoor condition bins of Kaohsiung City, Taiwan, was compiled as shown in table 1. It was plotted on the psychrometric chart as shown in figure 3. The set point temperature was obtained to be 22.1 C (72 F), based on the typical room temperature of 26 C (78 F) and 50% RH.

A typical office building, with room conditions kept at 26 C, 50% RH , 20% outside air ventilation rate, and air-conditioning supply temperature of 13 C, was studied for annual energy calculations.

The annual air-conditioning energy consumption of Kaohsiung City of such a building, for either using contentional air-conditioning (CAC) system, temperature control economizer (TC) system, enthalpy control (EC) system, and modified temperature control (MTC) system was simulated with results listed in Table 2. Using CAC system as a comparison basis, the relative energy conservation effect of each control strategy is again compiled in table 3.

The import features indicated in table 3 are quite interesting:

1. All three systems failed to provide effective free cooling at intermediate and hot seasons when cooling are needed most.

2. The HC and MTC systems saved more energy as expected.

3. The MTC system performs almost as well as that of the HC system, at an annual rate of 36.5% versus 34.8%, or a relative deviation of less than 5%.

EXPERIMENTAL INVESTIGATION AND DISCUSSIONS

In order to validate the simulation result, the HC system was actually applied on a full-scale test house for experimentation.

The test house was located in Kaohsiung, Taiwan, (around 23.5 degree North latitude) the main campus of National Sun Yat-Sen University, sponsored by the Energy Committee of Taiwan for long term building energy conservation experiments. The house sizes 17 m X 12 m X 10 m, and is equipped with two identical rooms sized 6 m X 5 m X 3.5 m simulating the perimeter zones of local office buildings in this area. Both rooms were equipped with two sepaate air-conditioning systems and replaceable exterior envelopes so that different passive and active design strategies can be applied on each room with energy conservation effect easily identified through comparison. The test house also provides a good full-scale experimental space for computer simulation validation as shown in figure 4.

Enthalpy controller was installed on the air-conditioning system of room A since April till October, 1988, with room temperature and air-conditioning power consumption recorded for each five minutes through a data acquisition system using IBMPC developped by the author. Room B was maintained with conventional air-conditioning system as a comparison basis. The reason for skipping the cold months is due to the small cooling demand in this area at that time.

The experimental results compared fairly well with the simulation as is discussed in the following.

1. The HC system was never being actuated during the months of May till October when cooling was needed most. Figure 5 shows the measured outdoor air enthalpies of July 1988, which stay far beyond the threshold enthalpy for free cooling.

2. In April, the system was actuated sometimes as expected. Although with minimal energy saving effect, it did demonstrate fairly well that the system actually works. The cool night air that it brought in further indicated that lower indoor temperature and enthalpy was maintained, which contribute to energy savings. Figure 6a and 6b show the typical performance of this system on April 13, 1988. The enthalpy sensor, being set at 64 kj/kg, drew in cool night air until around 10 a.m.. So, from midnight till 10 a.m. in the morning, room A was maintained at a temperature of around 26 C, which is also about 1.5 C lower than that of room B without enthalpy control as shown in figure 6a.

In figure 6b, it can be seen that after 10 a.m., as the outdoor enthalpy increased and exceeded 64 kj/kg, the threshold enthalpy, and the outdoor air damper was again closed. Figure 6a addressed this change accordingly by showing that room A and B temperature almost coincided thereafter, since both rooms were now supplied by two identical air-conditioning systems.

As expected from the simulation results, after mid-April, the HC system had lower and lower utilization rate and eventually remained intact.

CONCLUSION

The methodology presented in this study offers a powerful design tool for building energy conservation designs using enthalpy control. The TMY compiled provides a statistically most representative weather year so that annual performance of design strategies can be simulated and evaluated.

The simulation result indicated that very limitted energy savings can be obtained in the hot and humid areas in applying enthalpy control design strategies. Especially from May to October when cooling is most needed in this area, almost no energy savings can be experienced. The full-scale experimentation validated this result.

Again, as predicted from the simulation result, that in intermediate seasons such as in April or November, the enthalpy control system starting to gain some advantages. The experimentation also validated this result by indicating lower indoor temperature and enthalpy according to the on/offs of the enthalpy control damper while nighttime ventilation was applied. In this aspect, these design strategies still have the application potential for saving energy where cooling is needed all year round, such as in a crowded department store interior zones. In Kaohsiung City, Taiwan, this will account for approximately 30 % annual energy savings.

It is also indicated from the simulation result, that the MTC or modified temperature control system is very promising in actual application. The system performs almost as well as the more expensive and complicated enthalpy control sensors, and is easy to calibrate in the construction field since it is essentially a temperature sensor only set at a well- calculated point for better performances. The validation of its performance and to compare with the HC system should be interesting and can be performed in moderate climatic areas where enthalpy control have higher annual utilization rate.

After experimental validation, the simulation methodology developped in this paper is now extended and applied to other cities. The simulation result provides important feasilility study information to local building design engineers in optimizing their system design and is appreciated.

ACKNOWLEDGEMENT

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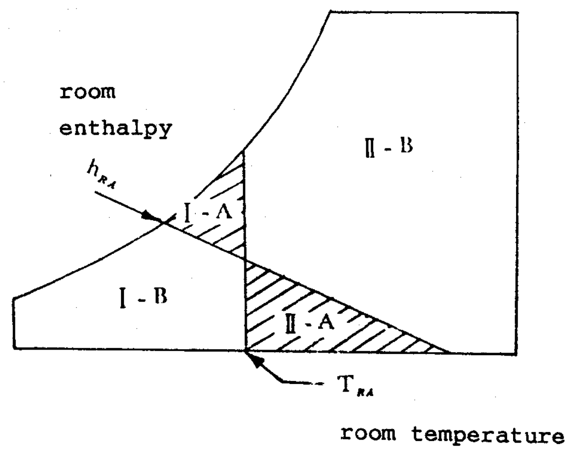

Figure 1 The Temperature Control (TC) and the Enthalpy Control (HC) Strategies

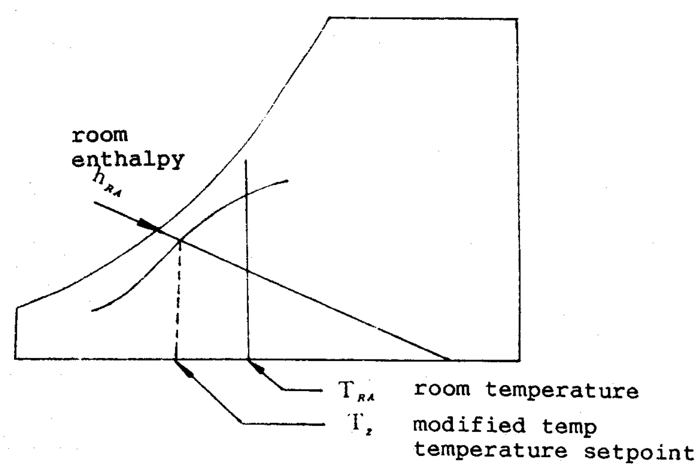

Figure 2 The Modified Temperature Control (MTC) Strategy

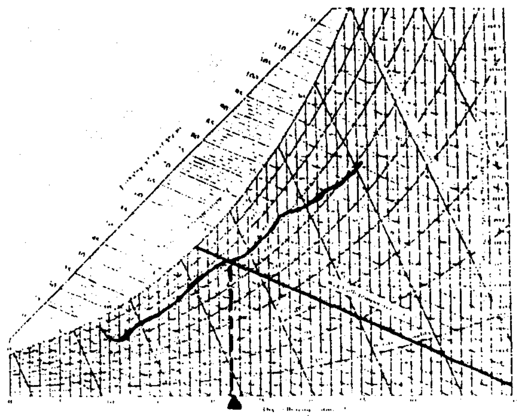

Figure 3 The MTC Strategy Psychrometric Process Applied in Kaohsiung, Taiwan (app. 23 N)

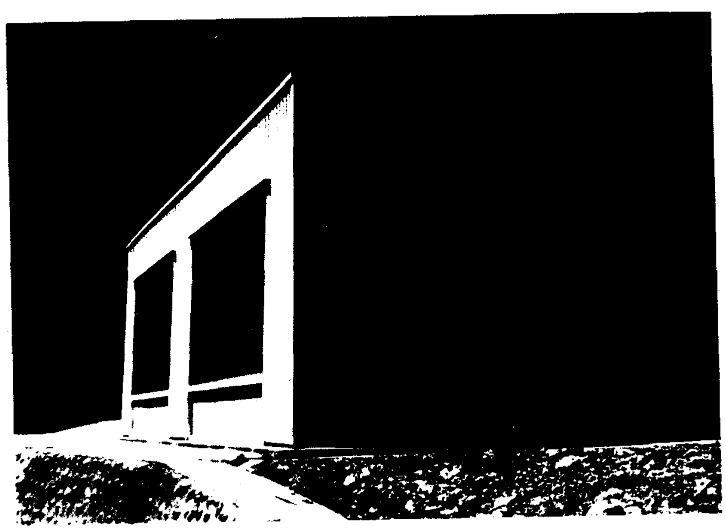

Figure 4 The NSYSU Energy Test House

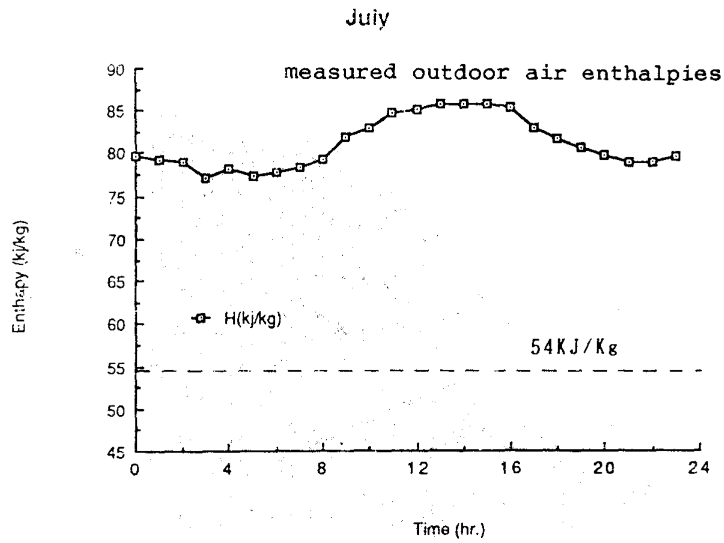

Figure 5 The Outdoor Air Enthalpies in July, 1988 Kaohsiung, Taiwan

Table 1 Hourly Bins of Outdoor Conditions in Kaohsiung Area

unit: temp. C

humidity ratio g/kg of dry air

temp. bins	total hours	average humidity ratio
2/4	0	0.0
4/6	0	0.0
6/8	0	0.0
8/10	1	6.1
10/12	35	5.4
12/14	139	6.7
14/16	323	7.9
16/18	561	9.0
18/20	574	10.7
20/22	696	11.9
22/24	841	12.5
24/26	1345	14.6
26/28	1734	16.5
28/30	1414	17.1
30/32	893	18.6
32/34	200	19.3
34/36	4	21.4
36/38	0	0.0
38/40	0	0.0
40/42	0	0.0

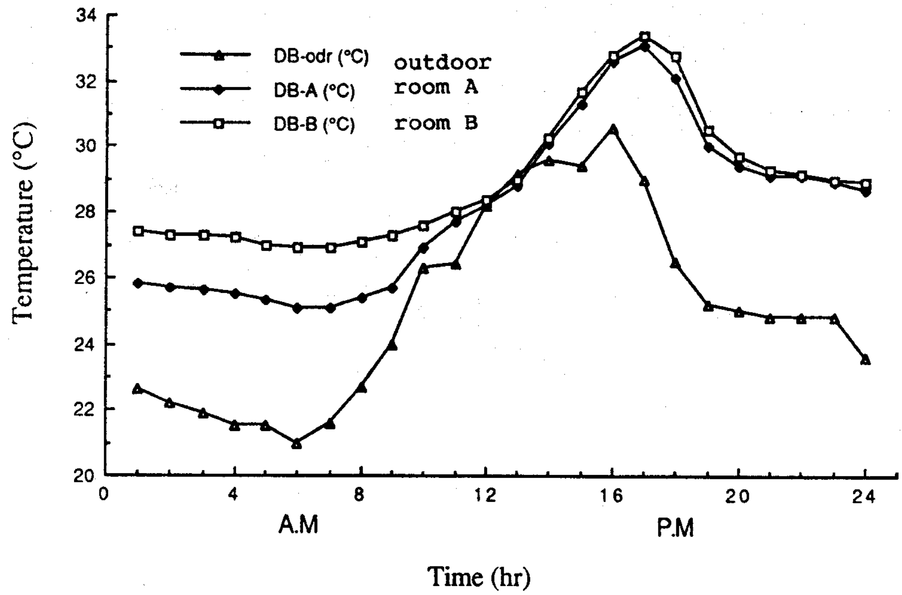

Figure 6a The HC System Performance on April 13,1988
NSYSU Energy Test House, Temperature Record

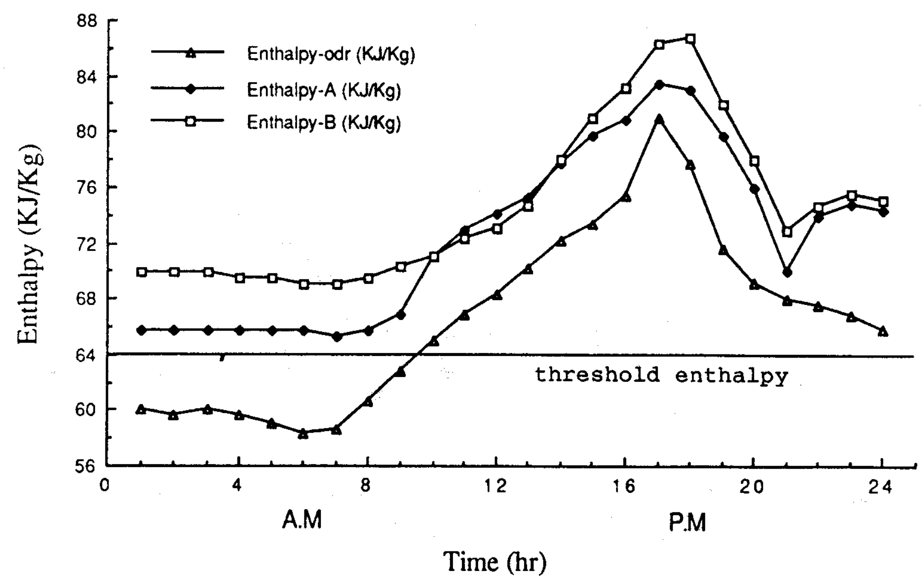

Figure 6b The HC System Performance on April 13, 1988
NSYSU Energy Test House, Enthalpy Record

Table 2 Annual Performances of Various Control Systems Applied on a Typical Office Building in Kaohsiung

month	CAC	TC	EC	MTC
1	13291	7021	6965	7380
2	12373	8089	7800	7883
3	14806	13259	12149	12315
4	16240	18027	16007	16073
5	17741	19709	17741	17747
6	18154	19149	18154	18154
7	19091	20362	19091	19091
8	18770	20543	18770	18770
9	17694	19312	17694	17694
10	17289	19414	17070	17106
11	14891	15027	13581	13916
12	13773	9204	8746	8975

unit: kj/kg of dry air

Table 3 Annual Energy Savings of Various Control Systems Applied on a Typical Office Building in Kaohsiung

month	TC	EC	MTC
1	47.2	47.6	44.5
2	34.6	37.0	36.3
3	10.5	17.9	16.8
4	-11.0	1.4	1.0
5	-11.1	0.0	0.0
6	-5.5	0.0	0.0
7	-6.7	0.0	0.0
8	-9.4	0.0	0.0
9	-9.1	0.0	0.0
10	-12.3	1.3	1.1
11	-0.9	8.8	6.5
12	33.2	36.5	34.8

unit: %