

Prediction of Thermal Comfort for Task-Ambient Air Conditioning

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Abstract: It is widely known that environment the traditional air conditioning providing is uniformly, so it is not convenient for meet thermal comfort of different occupants. Task-ambient air conditioning (TAC) system can produce a better individual thermal environment because it can implement individualized control for different occupants. Simultaneity, because of the time occupants in ambient area is short, standard of environment in ambient area can bease correspondingly thus can economize a great deal of energy. This paper aims at the difference of thermal environment between task and ambient area, analysis the thermal sensation under different areas and different temperatures by RWI (Relative Warmth Index) and HDR (Heat Deficit Rate) in the room of using task/ambient air conditioning system. Especially aim at the character of the time in ambient area is short, emphasize analyze the temporary comfort in ambient area. From the calculation result of RWI, we can get that the movable state influence on thermal sensation in the ambient area more and greatly, the calculation result of HDR put forward a temperature scope in thermal equilibrium according difference time occupants in ambient area. Integrate the calculation result of RWI and HDR, the writer suggests that the temperature of the ambient area can't over 30°C. So the influence of movable state must be noticed while evaluation the thermal environment of the ambient area and the temperature of the ambient area can't be too high otherwise will lower the whole environmental acceptability.

Keywords: task area, ambient area, RWI, HDR, thermal sensation

NOMENCLATURE

Symbol	Description [Units]
M	Metabolic heat production [W/ m ²]
P	Water vapour pressure [Pa]
i_{cw}	Effective clothing insulation [clo]
i_a	Outer boundary insulation [clo]
RWI	Relative Warmth Index
HDR	Heat Deficit Rate [W/ m ²]

1. INTRODUCTION

At present, the air condition is already extensive apply at anywhere in the world, it to human body of health, social economy of fast development have already develop and the function that still will develop and can't neglect. Traditional air condition method generally according to the hot and moisture load of the whole room, the air that handled is send out by the upper part or on the sides of the room and flows in the whole room, absorbing indoor surplus heat surplus moisture, eject by the outlet after with full admixture of indoor air, so the temperature in the whole room is uniform. Because the person's age, sex, physiology condition, clothes, activity of different, also have the difference to the request of the thermal environment. Meanwhile, using in a large amount such as the computer, duplicator, etc. of modern office equipment, making the partial cold and heat load of each work station also had the very big difference. Therefore, the traditional uniform indoor

environment parameter and the central air condition that unifies to control the thermal environment can't satisfy the individual need of different person to hot environment. A kind of new air condition technique that aim at improving the tiny weather of task area-task/ambient air conditioning is appeared, and got to quickly develop in the Japan, the United States and Europe, its typical model structure, such as figure 1 show.

The most advantage in TAC system is that the staff member can by oneself adjust the thermal environment in task area, to satisfy personal thermal sensation. The cold and heat source and the air handling unit of the TAC system is same to the normal air condition system, the differentiation between them is that TAC system increases the small scaled of partial inlet device, the ambient area, hallway and others share space to be supply by ceiling diffuser or floor diffuser, form the ambient area air conditioning consequently; the adjustable desktop inlet, adjustable floor diffuser form the task air conditioning [1], [2]. The user of TAC system can adjust the air rate, supply air temperature difference and supply angle of task air conditioning according to the personal habit and favour, to attain the most satisfied environment, but the thermal environment of ambient area must keep at acceptable range. According to the characteristics of the TAC system, the paper analysis the human body comfort under different thermal environment between the task area and the ambient area.

The most of the time the clerk is placed in the task area, just occasionally leave it work location to passing or temporarily stopping over in the ambient area, the time is especially short. The standards of ISO-7730s describe and evaluate thermal environment with the index of PMV and PPD, but this index does not consider the special factor that the time in ambient area is very short, so it is unsuitable to evaluate the thermal environment of ambient area. Therefore, this paper uses RWI (Relative Warmth Index) [3] and HDR (Heat Deficit Rate) [4], [5] what have instituted by United States Department of Transportation to evaluate the whole thermal environment of TAC system.

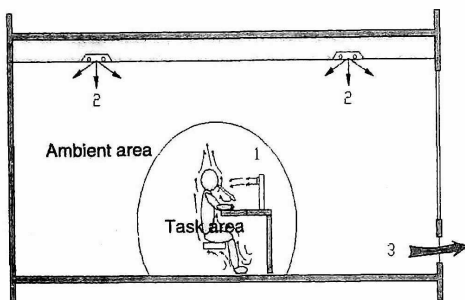


Figure 1: Task-ambient air conditioning

2. INTRODUCTION OF HDR AND RWI

2.1 RWI (Relative Warmth Index)

Relative Warmth Index introduce the concept of "temporary thermal sensation", so-called "temporary thermal sensation" mean the feeling that people enter another different environment from one environment. In design of the subway station environment, because it needs short time for the passengers to stay in the station hall and the platform, so we only consider the passenger's temporarily comfort when design the temperature and relative humidity inside the station in order to save energy, this is similar to the situation that staff are conducting activities in the ambient area. The RWI not only considers to the factor of influencing thermal comfort, such as environment temperature, relative humidity, the air velocity and the surface radiation temperature etc, and the special factor, short stay in the station is considered.

The RWI can be calculated by two different equations (1) or (2) according to different relative humidity condition:

When the water vapour pressure is higher than 2269Pa, using the equation:

$$RWI = \frac{0.317M(I_{cl} + I_{a}) + 1.13(t - 35) + 0.317R_{e}}{70 \left(1.73 - \frac{P}{3385.55} \right)} \quad (1)$$

When the water vapour pressure is equal to or lower than 2269Pa, using the equation:

$$RWI = \frac{0.317M(I_{cl} + I_{a}) + 1.13(t - 35) + 0.317R_{e}}{74.2} \quad (2)$$

Where M , is the metabolic heat production, W/m^2 ; P is the water vapour pressure, Pa; I_{cl} is the effective clothing insulation, the thermal resistance in clothing units, clo; I_{a} is the outer boundary insulation, thermal resistance at the outer boundary (clothing), clo; t is the dry-bulb temperature, $^{\circ}C$; R is the mean radiant flux, W/m^2 , m^2 is the human body skin area unit.

2.2 HDR (Heat Deficit Rate)

The HDR synthesized to consider the factors of influence human body thermal comfort, such as temperature, relative humidity, air velocity, radiant, metabolic heat production, clothing etc. The mean skin temperature for elementary comfort is in the scope of 30.6~35 $^{\circ}C$. Under the cold environment, the Centrum of human body thermoregulation will make the skin blood vessel shrink. Then the skin temperature will descend to reduce the human body heat lose. As the mean skin temperature descend to the comfortable lower limit 30.6 $^{\circ}C$, if the heat loses more than heat gain also, the body temperature further descends and the heat debt will appear. The HDR means the heat lose rate when the mean skin temperature equal to the lower limit of the comfortable mean skin temperature under the colder environment, that is human body heat storage rate.

The HDR Integral calculus of time is the heat debt, and $HDR \leq 0$ is the essential condition for the heat debt does not appeared. Because human body has a definite storage of heat, so people would feel cold when the heat debt exceeds 100 kJ / m^2 . Contrary, people would feel hot be the when the heat storage exceeds 100 kJ/ m^2 . HDR can be expressed as follows:

$$HDR = \frac{D}{H} = -M - \frac{6.42(t - 30.6) + R_{e}}{I_{cl} + I_{a}} + 28.39 \quad (3)$$

Where D , is the heat debt, J / m^2 , m^2 is the human body skin area unit; H is the exposed time, s. The meaning of other symbols is the same as the expression in RWI.

2.3 The value of metabolic rate

In choosing optimal conditions for comfort and health, the rate of work done during routine physical activities must be known, because metabolic power increases in proportion to exercise intensity. Metabolic rate varies over a wide range, depending on the activity, the person, and the conditions under which the activity is performed. The highest power a person can maintain for any continuous period is approximately 50% of the maximal capacity to use oxygen (maximum energy capacity). The activity of many people consists of a mixture of activities or a combination of work-rest periods. A weighted average metabolic rate is generally satisfactory, provided that activities alternate frequently (several times per hour). For example, a person typing 50% of the time, filing while seated 25% of the time, and walking about 25% of the time would have an average metabolic rate of $0.50 \times 65 + 0.25 \times 70 + 0.25 \times 100 = 75 W/m^2$. When metabolic rates must be determined more accurately than is possible with tabulated data, physiological

measurements with human subjects may be necessary. The rate of metabolic heat produced by the body is most accurately measured by the rate of respiratory oxygen consumption and carbon dioxide production. Table1 lists typical metabolic rates for an average adult for activities performed continuously [6]. The activity of the staff performed is seated and writing or typing in the task area, the activity is stand and get about frequently in the ambient area and the metabolism rate is the same as walking at 3 km/ h.

Table1: Typical Metabolic Heat Generation for Various Activities

Activity	M (W / m ²)
Seated, quiet	58.1
Writing or Typing	69.7
Standing, relaxed	98.9
Walking (on level surface)	
3km/h	116.1
4.8 km/h	151.3
6.5 km/h	220.6

2.4 Clothing Insulation

Table2: Typical Insulation Values for Clothing Ensembles

Ensemble Description	I _{cw} (clo)
Walking shorts, short-sleeved shirt	0.36
Trousers, short-sleeved shirt	0.51
Trousers, long-sleeved shirt	0.61
Trousers, vest and T-shirt	1.14

Because clothing insulation cannot be measured for most routine engineering applications, tables of measured values for various clothing ensembles can be used to select an ensemble comparable to the one(s) in question. Table 2 gives values for typical indoor clothing ensembles [6].

In table 2, I_{cw} is the intrinsic insulation of the ensemble. Walking decreases clothing insulation because it causes air flow around human body. The change in clothing insulation can be estimated from the intrinsic insulation of the ensemble and walking speed:

$$I_{cw2} = I_{cw1} + 0.246(v_1 - v_2) \quad (4)$$

When the activity of the staff performed is standing or walking about in the ambient area, the walking speed can be approximate estimated to 3 km/ h.

3. COMPUTATIONAL RESULT AND ANALYSIS

The task area is the main district that the staff members stayed, so at first, it must satisfy thermal comfort in this area. We use PMV to evaluate the thermal environment of task area. $M=69.7W/m^2$, $I_{cw}=0.51clo$, relative humidity between 40% and 70%,

air velocity is 0.3m/s, so PMV can be calculate from different temperatures, the mean radiant temperature can be consider equal to the ambient temperature.

when the task temperature is 24℃~26℃ and the ambient temperature is 28℃~30℃, PMV in task area all in 0 to 1, so 28℃~30℃ ambient temperature can satisfy the task area thermal comfortable. The result of calculation is in table 3.

Because the time in the ambient area of staff member is shorter, only consider staff members' thermal sensation of transient period, so we adopt RWI to calculate the thermal sensation of the ambient area. Neglect the influence of radiation, RWI of different temperature in ambient area calculated according to the formula (1) and (2) is list in table 4.

The connection between ASHRAE thermal sensation scale and corresponding RWI is shown in table 5.

When the activity of staff members in task area is writing and typing, RWI is between 0.08 and 0.10. When the activity of staff members in ambient area is quiet seating, RWI is between 0.09 and 0.13. From the calculation of RWI and corresponding ASHRAE thermal sensation scale we can receive that the change of thermal sensation between in task area and ambient area is not obvious. Especially when ambient temperature is 28℃, RWI is 0.09, equal to in 25℃ task area, less than in 26℃ task area. But if the activity of staff members in ambient area is walking, RWI is greater than in task area. This shows that people will obviously feel warmer while they enter the ambient area to walk from the task area.

Analyses the thermal sensation in the ambient area alone can be found out, if staff members sit quietly in the ambient area, RWI is 0.09 when the temperature is 28℃, the thermal sensation is close to neutral; RWI is 0.13 when the temperature is 30℃, the thermal sensation is close to slightly warm. It is obvious that even if the temperature of the ambient area reach 30℃, staff member's thermal sensation in case of sitting quietly will not exceed slightly warm. If staff members walking in the ambient area, RWI is 0.20 when the temperature is 28℃, the thermal sensation is among slightly warm and warm; RWI is 0.24 when the temperature is 30℃, the thermal sensation is close to warm. It is obvious that even if the temperature of the ambient area reaches 30℃, staff member will not feel hot either.

Because staff members only stay in a short time in the ambient area, it needn't offer very comfortable environment. Confirm the upper temperature of ambient area by HDR, the method is as follows: The heat storage of human body when hot is feeling is about 100 kJ / m², Suppose the heat deficit before staff member entering the ambient area is 0, if staff members need to stay for 20 minutes in the ambient area for the state of getting about frequently, it costs $HDR \geq 83.3 W / m$ at this moment, then according to the formula (3) we calculate that 30.1℃ is the upper temperature. Neglect influence of radiation, the upper temperatures according to different activities and times of staying list in table 6 and table 7.

When staff members need to walk frequently and the temperature of the ambient area is 28℃, they will

Table 3: PMV in the task area

ambient temperature (°C)	28			29			30		
task temperature (°C)	24	25	26	24	25	26	24	25	26
PMV	0.09	0.27	0.45	0.2	0.39	0.57	0.32	0.5	0.68

Table 4: Result of RWI calculated

	The task area			The ambient area			The ambient area		
Activities	Writing or Typing			Seated, quiet			Walking		
Environment temperature(°C)	24	25	26	28	29	30	28	29	30
$M (W / m^2)$	69.7			58.1			116.1		
$I_{cw} (clo)$	0.51			0.51			0.31		
$I_a (clo)$	0.32			0.32			0.32		
RWI	0.08	0.09	0.10	0.09	0.11	0.13	0.20	0.22	0.24

Table 5: The connection between ASHRAE thermal sensation scale and RWI

ASHRAE thermal sensation scale	RWI
warm	0.25
slightly warm	0.15
neutral	0.08
slightly cool	0.00

not feel uncomfortable within nearly half an hour, even under the temperature of 30°C, they can still be moving about for 20 minutes but will not feel uncomfortable in the ambient area; when staff members have a rest or sit quietly in the task area, under the temperature of 30°C, they can still stay for an hour but will not feel uncomfortable.

The calculation of HDR provides a temperature range in terms of human body's total heat balance. Because of the human body even in case of overall heat balance, it is uncomfortable that some position of the body may be caused because the environment temperature is too high, so the temperature of the ambient area can't be too high, otherwise will reduce the acceptability of the environment. Analyzing the calculated results of RWI and HDR synthetically, I think the temperature of the ambient area should not over 28°C when there are a small amount of work or activity, for guaranteeing staff member's normal work in the ambient area is very essential. If staff members have a rest or sit quietly in the ambient area, the upper temperature can be 30°C at this moment.

The traditional air conditioner regards whole room as the regulative target, systematic energy

Table 6: HDR under the state of walking

The time of staying (minute)	Upper HDR (W/ m ²)	I_{cw} (clo)	I_a (clo)	M (W/ m ²)	Upper temperature (°C)
27	-61.2	0.31	0.32	116.1	28.0
20	-83.3	0.31	0.32	116.1	30.1
15	-111.1	0.31	0.32	116.1	32.9
10	-166.7	0.31	0.32	116.1	38.2

Table 7: HDR under the state of sitting

The time of staying (minute)	Upper HDR (W/ m ²)	I_{cw} (clo)	I_a (clo)	M (W/ m ²)	Upper temperature (°C)
66	-25.1	0.51	0.32	58.1	30.0
40	-41.7	0.51	0.32	58.1	32.2
20	-83.3	0.51	0.32	58.1	36.0

4. CONCLUSION

Can be find out from the calculation of RWI, the impact on RWI of activity in the ambient area is greater, so when the thermal environment of the ambient area is predicted, should pay attention to the influence of the personnel's activity.

consumption is greater. Adopt TAC system, we can regard the task area as the regulative range, the environment standard of the ambient area requires that can be reduced properly, thus can economize a large amount of energy.

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