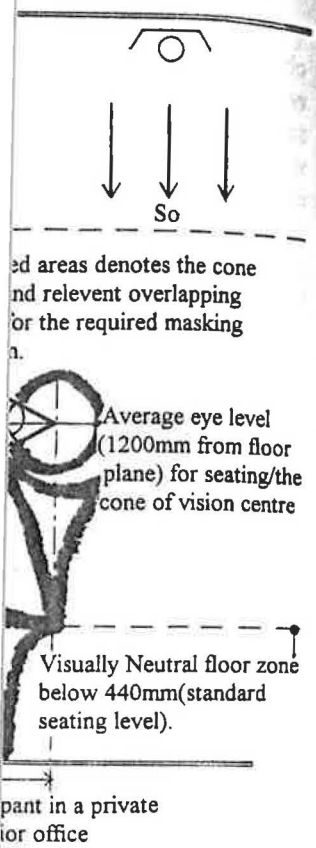

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EFFECT OF *KOTATSU* ON OCCUPANT AND ITS APPLICATION TO INDOOR CLIMATE PLANNING

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ABSTRACT *KOTATSU* is a well-known heating facility in Japan. It heats the lower extremities of a body by an IR heater or wood coal fire in a box. The objective of this paper is to clarify the thermal effect of *KOTATSU* on a person. Experiments were carried out under the following combined conditions: air temperatures were 11°C, 14°C, 17°C, and 20°C and IR lamp levels were 'off', 'low', 'middle' and 'high' which correspond to 0W, 87W, 91W and 181W IR heater electric power consumption, respectively. Five male and six female subjects participated in those experiments. The following results were obtained: 1) The mean skin temperature at the lower extremities of the body rose and that at the upper extremities dropped respectively, at the same time while a subject was seated at the *KOTATSU*. 2) The heating facility *KOTATSU* at 'middle' IR heater position has the equivalent effect of 8°C air temperature rise at 11°C air temperature, and also has more than 2°C effectiveness at 14°C air temperature even if the IR lamp of the *KOTATSU* is turned off. 3) Even if actual air temperature is below the optimal temperature, *KOTATSU* has a great potential for occupants to make the thermal comfort in the cold environment.

1. INTRODUCTION

KOTATSU is a well-known heating facility from the ancient times in Japan. This heating facility *KOTATSU* heats lower extremities by an IR heater or wood coal fire in a box covered with *Futon*. The *KOTATSU* with an IR lamp have come into wide use recently. Moreover, *KOTATSU* plays an important role in Japanese daily living environment in winter. The *KOTATSU* is much used as properties for conversation, taking a meal, manipulate working and etc. . As shown in Fig. 1, the typical heating facility *KOTATSU* is composed of a coverlet, a mattress, a wooden frame with an IR lamp and a board. Nevertheless, there is few studies [1-5] regarding thermal effect of *KOTATSU* on a person. The purpose of this paper is to

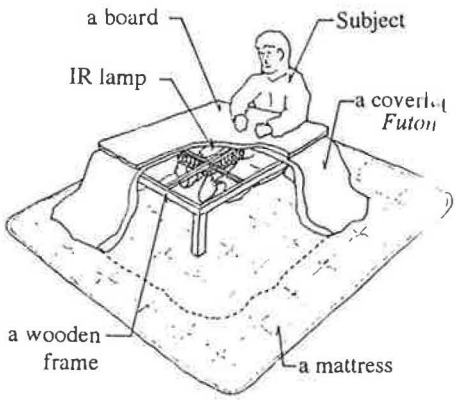

Fig. 1 An Illustration of The Typical Heating Facility *KOTATSU*

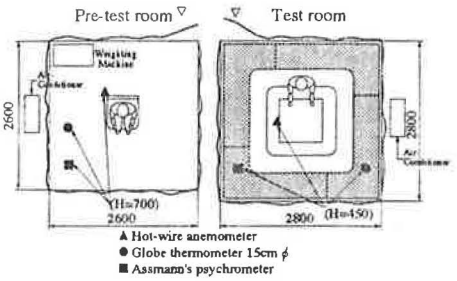

Fig. 2 Plan of Test Room

indicate and to clarify the thermal effect of *KOTATSU* on a person throughout experiments using eleven subjects.

2. EXPERIMENTAL DESIGN

From October, 1995 until April, 1996, a series of experiments were conducted in the environmental test chamber at Nagoya Institute of Technology. A test room (dimensions 2.8 x 2.8 x 2.0 m^3) and a pre-test room (dimensions 2.6 x 2.6 x 2.0 m^3) were built in the chambers above, air temperature can be controlled by the air conditioners. The floor plan of these test rooms are shown in Fig. 2. *KOTATSU* with an IR lamp was used in the experiments. The experimental conditions are listed in Table 1. In the pre-test room, air temperature was kept at 25°C. In the test room, air temperature and the IR lamp level were controlled the following combined conditions under 50% rh : air temperature were 11°C, 14°C, 17°C and 20°C and the IR lamp levels were "off", "low", "middle" and "high" which corresponds to 0W, 87W, 91W and 181W of IR heater electric power consumption, respectively. The air velocity in the occupied zone is less than 0.15 m/s. Five males and six females, ranged in age from 19 to 24 years old were adopted as subjects. The physical data for the subjects used in this study and the measured insulation values of the clothing are shown in Table

Table 1 Experimental Conditions

Air Temperature ℃	IR Lamp Condition*	Relative Humidity %	Air Velocity m/s	Subjects	
				Male	Female
11	Middle High	50	less than 0.1	IT,IM,OS FS,KT	AN,AR,OZ TG,GK
14	Turn Off Low Middle				
17	Turn Off Low Middle				AN,AR,OZ MT,TG
20	Turn Off Low Middle				

*IR Lamp Electric Power Consumption

'Turn Off'	0W
'Low'	86.2W
'Middle'	91.1W
'High'	181.4W

Table 2 Physical characteristics of subjects

Subject	Age	Height [cm]	Weight [kg]	Body Surface Area* [m^2]	Clo Value ** [clo]	Native Place	Sex
IT	22	170.5	59.5	1.69	0.89	Aichi	
IM	23	165.1	59.5	1.65	0.87	Aichi	
OS	21	176.7	56.1	1.69	0.89	Aichi	Male
FS	21	177.5	73.0	1.88	0.92	Aichi	
KT	22	174.2	75.5	1.88	0.89	Gifu	
AN	21	161.9	50.7	1.53	0.83	Gifu	
AR	19	162.0	58.0	1.61	0.83	Toyama	
OZ	19	149.6	41.7	1.35	0.83	Shizuoka	Female
MT	20	155.8	44.1	1.41	0.83	Gifu	
TG	23	155.0	50.8	1.49	0.83	Aichi	
GK	24	157.4	46.8	1.46	0.83	Aichi	

*Kurazumi formula [6]

$A=100.315W^{0.383}H^{0.693}$

W: weight [kg] H: height [cm]

**Hanada formula [7]

$Y=0.000558W+0.068$

W: total clothing weight [g]

Table 3 Clothing conditions

Clothing		Weight [g]
Working coat and trousers	S-size	950
	M-size	1020
	L-size	1060
	LL-size	1110
Long-sleeve, dress shirt		210
T-shirt		95
Brief(male)		60
Panties(female)		15
Bra(female)		43
Socks		50

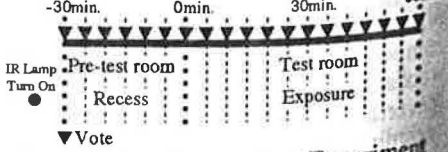

Fig. 2 Time Schedule of Experiment

Table 4 Instruments and
Measuring Therm
and Human Respo

Item	Instrument
	Environmental Condition
Air Temperature	Outside the *KOTATSU*
	Assmann's Psychrometer
	T-typed Thermocouple(0.2
Relative Humidity	Assmann's Psychrometer a
Globe Temperature	T-typed Thermocouple(0.2
Air Velocity	Globe Thermometer
Surface Temperature	Hot-wire Anemometer
	T-typed Thermocouple(0.3
Air Temperature	Inside the *KOTATSU*
	T-typed Thermocouple(0.2m
Globe Temperature	Globe Thermometer
Air Velocity	Hot-wire Anemometer
Surface Temperature	T-typed Thermocouple(0.3m
Electric Power Consumption	Electric Power Consumption
Skin Temperature	Physiological Responses
	T-typed Thermocouple(0.2mm
Oral Temperature	T-typed Thermocouple(0.2mm
Clothing Surface	T-typed Thermocouple(0.2mm
Heat Flow Rate	Heat Flow Meter
Weight Loss	Weighing Machine

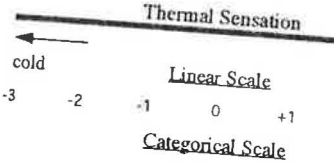

Fig. 3 Voting Scales for Thermal

2. All subjects wore a clothing
as shown in Table 3. The subje
in the pre-test room for 30 minu
air temperature = 25°C and air v
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the test room. The subjects were
to read a book during the exposu
The measuring instruments and
for thermal conditions and
responses are shown in Table 4. T
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measured by means of 0.2mm ϕ
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surgical tape. The subjects report
thermal sensation, comfort sensati
radiant perception on the whole bo
lower body and the upper bo

xperimental Conditions

	Relative Humidity %	Air Velocity m/s	Subjects	
			Male	Female
	50	less than 0.1	IT,IM,OS FS,KT	AN,AR,OZ TG,GK
				AN,AR,OZ MT,TO

ric Power Consumption

0W
86.2W
91.1W
181.4W

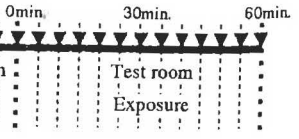
cal characteristics of subjects

ght	Body Surface Area* [m²]	Clo Value ** [clo]	Native Place	Sex
5	1.69	0.89	Aichi	
5	1.65	0.87	Aichi	
1	1.69	0.89	Aichi	Male
0	1.88	0.92	Aichi	
5	1.88	0.89	Gifu	
7	1.53	0.83	Gifu	
0	1.61	0.83	Toyama	
7	1.35	0.83	Shizuoka	Female
1	1.41	0.83	Gifu	
3	1.49	0.83	Aichi	
3	1.46	0.83	Aichi	

ula [6]
$5W^{0.383}H^{0.693}$
veight [kg] H: height [cm]
la [7]
58W+0.068
otal clothing weight [g]

Clothing conditions

g		Weight [g]
rousers	S-size	950
	M-size	1020
	L-size	1060
	LL-size	1110
ess shirt		210
		95
e)		60
ale)		15
e)		43
		50



Schedule of Experiment

Table 4 Instruments and Methods for Measuring Thermal Conditions and Human Responses

Item	Instrument	Position
	Environmental Conditions	
	Outside the *KOTATSU*	
Air Temperature	Assmann's Psychrometer	45cm High
	T-typed Thermocouple(0.2mm ϕ)	10cm, 100cm, 180cm High
Relative Humidity	Assmann's Psychrometer and T-typed Thermocouple(0.2mm ϕ)	45cm High
Globe Temperature	Globe Thermometer	45cm High
Air Velocity	Hot-wire Anemometer	45cm High
Surface Temperature	T-typed Thermocouple(0.3mm ϕ)	
	Inside the *KOTATSU*	
Air Temperature	T-typed Thermocouple(0.2mm ϕ)	9cm, 14cm, 24cm High
Globe Temperature	Globe Thermometer	9cm High
Air Velocity	Hot-wire Anemometer	9cm High
Surface Temperature	T-typed Thermocouple(0.3mm ϕ)	
Electric Power Consumption	Electric Power Consumption Meter	
	Physiological Responses	
Skin Temperature	T-typed Thermocouple(0.2mm ϕ)	Hardy-DuBois's 12point[8]
Oral Temperature	T-typed Thermocouple(0.2mm ϕ)	
Clothing Surface	T-typed Thermocouple(0.2mm ϕ)	Hardy-DuBois's 12point[8]
Heat Flow Rate	Heat Flow Meter	Ramanathan's 4point[9] +Posterior thigh
Weight Loss	Weighting Machine	

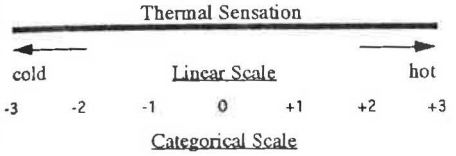


Fig. 3 Voting Scales for Thermal Sensation

2. All subjects wore a clothing ensemble as shown in Table 3. The subjects stayed in the pre-test room for 30 minutes under air temperature = 25°C and air velocity < 0.1m/s in a sedentary position. After this period, the subjects were exposed to the experimental conditions for 60 minutes in the test room. The subjects were allowed to read a book during the exposure time. The measuring instruments and methods for thermal conditions and human responses are shown in Table 4. The skin temperatures of each subject were measured by means of 0.2mm ϕ T-typed thermocouples attached to the skin by the surgical tape. The subjects reported their thermal sensation, comfort sensation and radiant perception on the whole body, the lower body and the upper body by

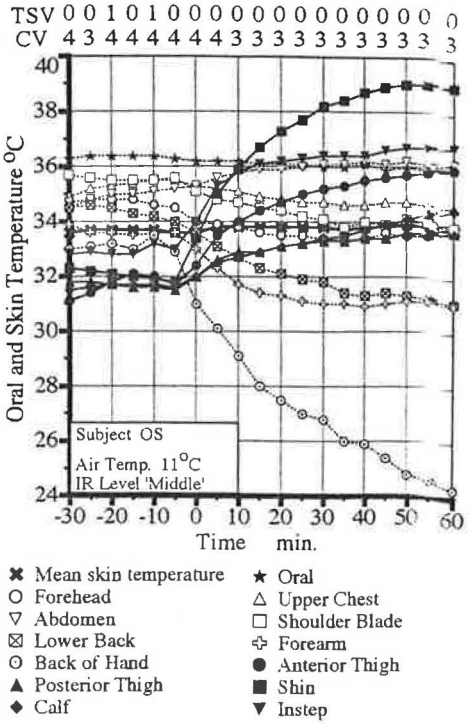


Fig. 4 The changes of oral and skin temperatures for the subject OS at air temperature 11°C and IR lamp level 'middle' with the passage of the time.

checking liner scales and categorical scales [10] on the ballot as shown in Fig. 3.

3. RESULTS

The changes of oral and skin temperatures for the subject OS at air temperature 11°C and IR lamp level 'middle' with the passage of the time are shown Fig. 4, as an example. The values above each graphs represent psychological reactions on a subject reported by categorical scales. The skin temperatures at the anterior thigh, posterior thigh, shin, calf and instep in the *KOTATSU* rose with the passage of the time from entering the

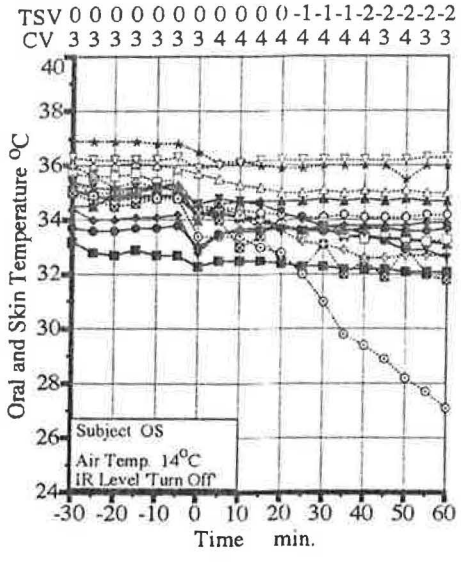


Fig. 5 The changes of oral and skin temperatures for the subject OS at air temperature 14°C and IR lamp level 'turn off' with the passage of the time.

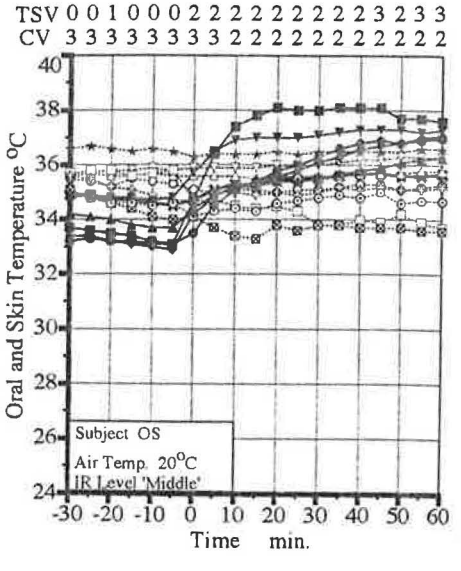


Fig. 6 The changes of oral and skin temperatures for the subject OS at air temperature 20°C and IR lamp level 'middle' with the passage of the time.

test room. The skin temperature at the shin nearest to the IR lamp rose up to 39°C throughout the exposure time. The oral temperature and the skin temperatures at the forehead and abdomen as a trunk, were constant. The skin temperatures at the upper chest, shoulder blade and lower back dropped. The skin temperatures at the forearm and back of the hand as extremities, dropped with the passage of the time. Especially, the skin temperature at the back of hand dropped largely to the approximately 24°C during 60 minutes of exposure time. The mean skin temperature was being at constant throughout the exposure time. The thermal sensation vote reported by the categorical scale is constant at the thermal neutrality.

The changes of oral and skin temperatures for the subject OS at air temperature 14°C and IR lamp level 'turn off' with the passage of the time are shown Fig. 5. The oral temperature and the skin temperatures at the abdomen and forehead is constant. The skin temperature at the back of hand exposed to cold room air dropped 6°C, and that at the forearm dropped 1.5°C. The mean skin temperature dropped approximately by 1°C during the exposure time. As for the thermal sensation, the subject reported cooler sensation.

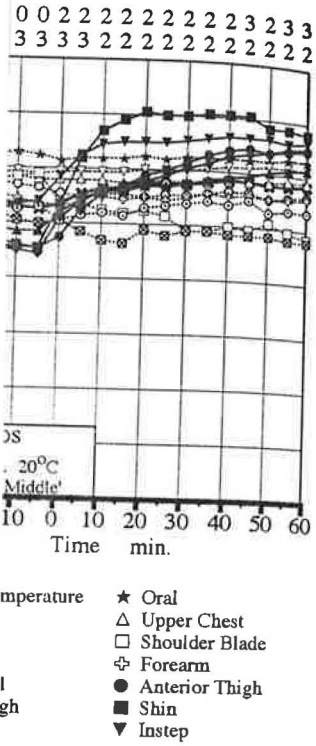
The changes of oral and skin temperatures for the subject OS at air temperature 20°C and 'middle' with the passage shown Fig. 6. All of the sk at positions located inside rose with the passage of the temperature and all skin except the above pos approximately constan exposure time. The mean sk rose approximately by 1° exposure time. The subj warmer sensation with the time.

Throughout the all expo oral temperature and the skin at the trunk were kept at co the subject was seating at the The skin temperatures a extremities exposed to cold with decreasing the air temp skin temperatures at positi inside the *KOTATSU* rose ev lamp was turned off. This pl results in thermoregulatory control heat balance between body and its surroundings.

5. DISCUSSION

The values of the l throughout of exposure time we the analysis. To calculate th mean skin temperature un *KOTATSU* heating facility, th weighting coefficients intro Hardy-DuBois [8] were modifi measured values of the contact areas. The relationship bet modified mean skin temper thermal sensation vote at the w for all subjects is shown in F regression line in this graph in increase in the thermal sensation increasing the modified m temperature. The modified n temperature is 34.0°C when reported thermal neutrality appr 50 arbitrary scale.

For the present analysis, a r



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temperature 20°C and IR lamp level 'middle' with the passage of the time are shown Fig. 6. All of the skin temperatures at positions located inside the *KOTATSU* rose with the passage of the time. The oral temperature and all skin temperatures except the above positions were approximately constant during the exposure time. The mean skin temperature rose approximately by 1°C during the exposure time. The subject reported warmer sensation with the passage of the time.

Throughout the all exposure tests, the oral temperature and the skin temperature at the trunk were kept at constant while the subject was seating at the *KOTATSU*. The skin temperatures at the upper extremities exposed to cold air decrease with decreasing the air temperature. The skin temperatures at positions located inside the *KOTATSU* rose even if the IR lamp was turned off. This phenomenon results in thermoregulatory system that control heat balance between the human body and its surroundings.

5. DISCUSSION

The values of the last votes throughout of exposure time were used for the analysis. To calculate the accurate mean skin temperature under using *KOTATSU* heating facility, the 12-point weighting coefficients introduced by Hardy-DuBois [8] were modified with the measured values of the contacted surface areas. The relationship between the modified mean skin temperature and thermal sensation vote at the whole body for all subjects is shown in Fig. 7. The regression line in this graph indicates an increase in the thermal sensation vote with increasing the modified mean skin temperature. The modified mean skin temperature is 34.0°C when subjects reported thermal neutrality approximately 50 arbitrary scale.

For the present analysis, a new single

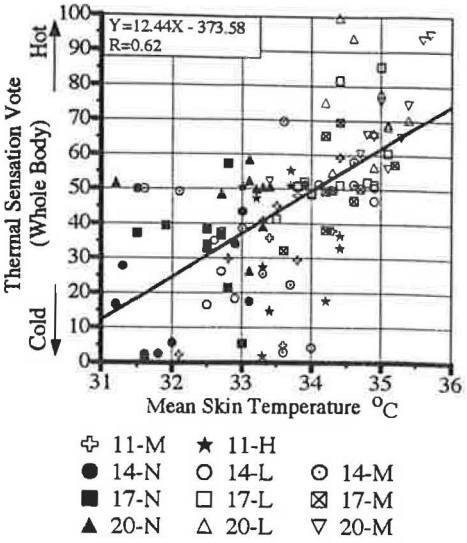

Fig.7 Relation between Mean Skin Temperature and Thermal Sensation Vote on Whole Body

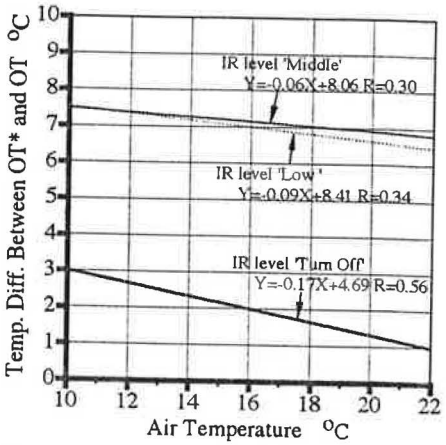

Fig. 8 Relation between Air Temperature and Temperature Difference Between the Corrected Operative Temperature and the Operative Temperature

temperature [1] that is physically representative of the effect of air temperature, mean radiant temperature and contacted temperature combined is used. Fig. 8 shows temperature difference

between the corrected operative temperature and the operative temperature, versus air temperature. The temperature difference between both operative temperatures represents the thermal effectiveness of *KOTATSU* heating from viewpoint of the humans. The regression lines for each IR lamp level in this graph were calculated by experimental data at the last measurements of the exposure time. It is obvious that the thermal effectiveness for each IR lamp level decrease with increasing the air temperature. The *KOTATSU* has equivalent effect of 8°C air temperature rise at 11°C of air temperature and IR lamp level of 'middle'. There is little difference between thermal effect of 'low' and 'middle' levels because IR heater electric power consumption of these levels is almost the same value. Even though the IR lamp in *KOTATSU* is turned off, the *KOTATSU* has also more than 2°C effectiveness at 14°C of air temperature . This phenomenon results in heat generation from the human body and insulation effect of this facility.

In an actual living environment, we frequently experience cold environment in winter even in indoors. Even if actual air temperature is below the optimal temperature, *KOTATSU* has a great potential for occupants to make the thermal comfort in winter. And this potential may be increase with increasing the occupants' clothing insulation. Consequently, we are able to enjoy comfortable environment in winter by means of *KOTATSU* heating facility without an air conditioner.

6. CONCLUSIONS

The following conclusions were obtained throughout the experiments :

1) The skin temperature at a lower body rose and the skin temperature at an upper body dropped respectively, at the same time while a subject seated at the *KOTATSU* in the cold environment.

2) The *KOTATSU* has equivalent effect of 8°C air temperature rise at 11°C of air temperature and IR lamp revel of 'middle', and also has more than 2°C effectiveness at 14°C of air temperature even though the IR lamp in *KOTATSU* is turned off.

3) Even if actual air temperature is below the optimal temperature, *KOTATSU* has a great potential for occupants to make the thermal comfort in the cold environment.

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A STUDY ON TI
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ABSTRACT The o
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1. INTRODUCTION

Nowadays, the global env
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The authors investiga
in Japan, and found that in
that residents were far fro
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importance of the invest
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The objective of this s
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the results.

2. METHODS

We send the questionnaires
heating apparatus and so fo