Potential Influence of Moisture Sorption and Desorption of Walls on Space Conditioning Load of Residential Buildings

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ABSTRACT

The hygrothermal performance of houses is recently being required to indicate quantitatively due to the encouragement of energy conservation. Several calculation methods are practically proposed to evaluate energy saving measures of houses. However, those methods do not take into account moisture transfer in wall assemblies. Humidity calculation is simply affected by ventilation and focuses on just the building spaces. In this paper, the potential influence of moisture sorption and desorption of walls on space conditioning load is evaluated in several regions where the climate conditions are distributed from cold to seasonally sultry in Japan. The dynamic simulation software based upon detailed physical models on heat and moisture transfer and airflow, which can predict the hygrothermal environment of whole buildings based whether or not moisture sorption and desorption of walls are taken into account, is utilized for comparative numerical experiments. Then it is clarified that the calculation error accounts to over 10 percent both heating and cooling of the total heat load. The influence of moisture sorption and desorption of walls is unable to disregard to predict the space conditioning load.

1. INTRODUCTION

Japanese houses of recent years tend to be insulated and built airtight to improve indoor thermal environment and to decrease heating and cooling load. Due to the enforcement of the "Energy Conservation Standard for Housing (IBEC, 2007)" and the "Housing Performance Indication Law" in Japan, insulation and air-tightness have been all the more emphasized, and concomitantly, the qualitative descriptive explanation in the past about the housing thermal performance has shifted to numerical quantitative evaluation. Thus the performance is being represented by steady state calculation methods which describes "specification standard" or "thermal loss coefficient" or by unsteady state calculation methods which reflects dynamic heat transfer phenomena such as ventilation, solar heat gain, thermal storage in building structures and internal heat generation from human living. However those general methods do not take into account moisture transfer in wall assemblies (LCHPEO, 2004). Humidity calculation in most of them is simply affected by ventilation and focuses on just the building spaces. In this paper, the differences of sensible and latent heat of space conditioning in residential buildings are clarified by dynamic simulation based whether or not moisture sorption and desorption of walls are involved. Thus the potential influence of moisture transfer of walls on heating and cooling load is evaluated.

2. SIMULATION SOFTWARE "THERB" OF HIGROTHERMAL ENVIRONMENT

THERB (computer software program of the hygrothermal environment of the residential buildings) is dynamic simulation software which can estimate temperature, humidity, sensory index, and heating/cooling load for multiple zone buildings and wall assemblies (Ozaki, 2006). The heat and moisture transfer models used in THERB such as conduction, convection, radiation and ventilation (or air leakage) are based upon the detailed phenomena describing actual building physics, and can be applied to all forms of building design, structure or occupant schedules, etc. All the phenomena are calculated without simplification of the heat and moisture transfer principles of any building component or element. The P-model utilizing the water potential, which is defined from nonequilibrium thermodynamics as the driving force of moisture transfer, is a progressive feature of THERB, which incorporates moisture transfer including moisture sorption and desorption of walls. Temperature, water vapor pressure and atmospheric pressure are integrated into the water potential as the thermodynamic energy with homogeneous dimension (Ozaki, 2003).

Indoor air temperature and humidity can be calculated from heat and moisture balance of a space based on convection, ventilation, internal generation of heat and moisture. By default, indoor humidity is interrelated with sorption and desorption of walls through the application of the P-model. Simplified humidity calculation that is just affected by ventilation is also available. Sensible and latent heat load are obtained from the equations of heat and moisture balance, in which unknown quantities are space heating and cooling load, on condition that temperature and humidity are set at reference ones. By default, humidity control and temperature control are linked. Temperature and humidity set-point and ranges can be optionally set every hour. Thus THERB can predict the transient hygrothermal environment of the whole building taking into consideration the complex relationship between heat and moisture transfer and airflow.

3. INFLUENCE OF MOISTURE SORPTION AND DESORPTION OF WALLS ON SPACE CONDITIONING LOAD

The potential influence of moisture sorption and desorption of walls on sensible and latent heat of space conditioning is analyzed through comparative numerical experiments. The calculation conditions such as a building model and a living schedule are conformed to a procedure of the officially approved benchmark test which validates an accuracy of dynamic simulation software in Japan.

Preset temperature and humidity for space conditioning is changed and heating and cooling load is compared in Sapporo, Tokyo and Fukuoka, in which the climate conditions are distributed from cold to seasonally sultry, utilizing the following three calculation methods; the simplified calculation 1 assuming the moisture capacity of indoor air is 16.7g/(m^3. kg/kg(DA)) instead of no moisture transfer calculation of walls, the simplified calculation 2 based on zero additional moisture capacity to indoor air and the detailed calculation with moisture transfer calculation of walls. The amount of the hypothetical moisture capacity of indoor air 16.7g/(m^3.kg/kg(DA)) is generally used to approximate the latent heat corresponding to moisture sorption and desorption of walls in Japan.

3.1 Calculation conditions

The figure 1-3 and table 1 show the first and second floor plan, vertical cross-section of north-south and exterior wall assemblies. Building model is a detached wooden house of two stories and the first and second floor area are 63m^3, respectively. A damp-proof membrane is installed at the back side of interior backing material. Table 2 illustrates human living (time schedule of intermittent space conditioning), hourly internal heat generation and regional ventilation amount (adding to all day ventilation amount of 0.5 air change rate per hour). Above mentioned calculation conditions conform to the procedure of the officially approved benchmark in Japan. Table 3 and 4 show the heating and cooling conditions. The preset temperature and humidity are changed in the following range; 18-22 degree C and 40-60% for heating, 26-28 degree C and 50-70% for cooling. Although humidity can not be usually controlled in residential houses, especially for cooling, the ordinary hygrothermal conditions (degree C-%) are empirically estimated from 18-60 to 22-40 in heating and from 26-70 to 28-50 in cooling in Japan. Humidity control (humidifying and dehumidifying) relates to temperature control (heating and cooling). Thus if indoor temperature rises above the heating preset temperature in winter and falls below the cooling preset temperature in summer, the indoor hygrothermal environment is left to nature. Hourly standardized weather data in Sapporo, Tokyo and Fukuoka are used for the dynamic simulation.

3.2 Calculation results

Figure 4 and 5 illustrate the term sensible and latent heat load for heating and cooling in each region under the calculation conditions "Case A-I (all day space conditioning)" and "Case J-R (intermittent space conditioning)" by the detailed calculation taking account of moisture transfer of walls. The heating latent heat load accounts for 7.2 to 24.1% in Sapporo and 7.2 to 37.4% in Tokyo and Fukuoka of total heat load.

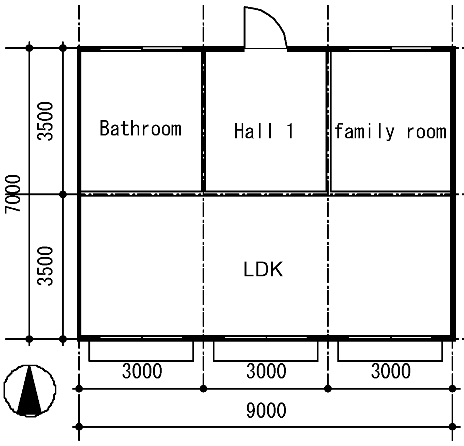


Fig.1 The first floor plan (mm)

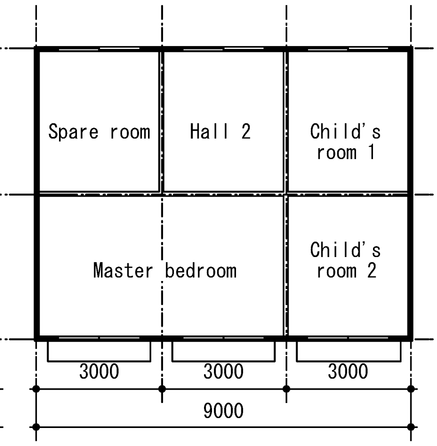


Fig.2 The second floor plan (mm)

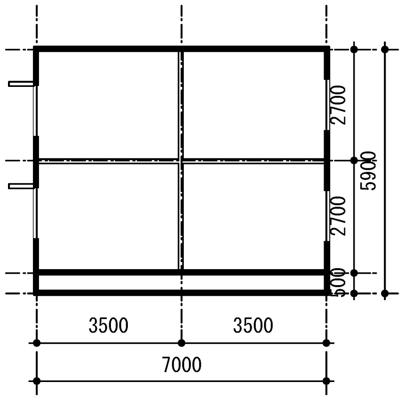


Fig.3 North-south cross section (mm)

Table 1 Wall Assemblies (mm)

Exterior Wall	Mortar (30) + Plywood (9) + Air cavity (20) + Glass wool (16kg/m^3, 100) + Weather barrier + Plaster-board (12)
Interior Wall	Plaster-board (12) + Air cavity (100) + Plaster-board (12)
Roof	Steel Plate (1) + Plywood (12) + Air cavity (100) + Glass wool (10kg/m^3, 200) + Plaster-board (12)
The 1st Floor	Plywood (22) + Glass wool (16kg/m^3, 150)
The 2nd Floor	Plywood (22) + Air cavity (50) + Plaster-board (12)

Table 2 Living schedule, internal heat generation and regional ventilation amount

Number of persons	-5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23-	(Time)
LDK	0	1	4	1						0		3						1	0	
Children's room 1,2	1		0													1				
Master bedroom	2	1	0															1	2	

Inner heating [W]	-5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23-	(Time)
LDK	45	985	385		145			445	145			445	1105		505		445		45	
Bathroom	0	40			100		0					40					200		0	
Hall 1,2	0	60			0							60							0	
Children's room 1,2	0		80	0												180		0		
Master bedroom	0	100	0														100		0	

Regional ventilation amount [m^3/h]	-5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23-	(Time)
LDK	0	400	0					200	0				400		0					

Table 3 Preset temperature and humidity for heating

All day	Preset temperature and humidity for heating		Intermittent	Preset temperature and humidity for heating	
Case	Tem. (de. C)	Humid. (%)	Case	Tem. (de. C)	Humid. (%)
Ah	18	40	Jh	18	40
Bh	18	50	Kh	18	50
Ch	18	60	Lh	18	60
Dh	20	40	Mh	20	40
Eh	20	50	Nh	20	50
Fh	20	60	Oh	20	60
Gh	22	40	Ph	22	40
Hh	22	50	Qh	22	50
Ih	22	60	Rh	22	60

Table 4 Preset temperature and humidity for cooling

All day	Preset temperature and humidity for cooling		Intermittent	Preset temperature and humidity for cooling	
Case	Tem. (de. C)	Humid. (%)	Case	Tem. (de. C)	Humid. (%)
Ac	26	50	Jc	26	50
Bc	26	60	Kc	26	60
Cc	26	70	Lc	26	70
Dc	27	50	Mc	27	50
Ec	27	60	Nc	27	60
Fc	27	70	Oc	27	70
Gc	28	50	Pc	28	50
Hc	28	60	Qc	28	60
Ic	28	70	Rc	28	70

The cooling latent heat load accounts for 6.6 to 47.4% in Tokyo and Fukuoka of the total heat load.

Figure 6 and 7 illustrate the term latent heat load for heating and cooling by the simplified calculation 1 assuming the moisture capacity of indoor air is 16.7g/(m^3.kg/kg(DA)) and the simplified calculation 2 based on zero additional moisture capacity to indoor air and the detailed calculation. Compared with the simplified calculation 1 and the detailed calculation, the difference of the term latent heat load for heating increases with humidity rise in isothermal condition and with temperature rise in the same humidity condition.

The difference between both calculations runs up to 28.5MJ/m^2 (31.3%), 22.3MJ/m^2 (30.2%), 19.3MJ/m^2 (32.8%) in order of Sapporo, Tokyo and Fukuoka and becomes the largest in Case R_h that is the highest hygrothermal condition under the intermittent heating, incidentally, and the difference of the term total heat load for heating between both calculations runs up to 31.4MJ/m^2 (8.3%), 24.8MJ/m^2 (11.7%), 21.1MJ/m^2 (11.4%) in order of Sapporo, Tokyo and Fukuoka.

Meanwhile, compared with the simplified calculation 1 and the detailed calculation, the difference of the term latent heat load for cooling in Tokyo and Fukuoka increases with humidity decrease in isothermal condition and with temperature decrease in the same humidity condition.

The difference between both calculations runs up to 11.3MJ/m^2 (30.5%) and 13.0MJ/m^2 (29.3%) in Tokyo and Fukuoka respectively and becomes the largest in Case J_c that is the lowest hygrothermal condition under the intermittent cooling, incidentally, and the difference of the term total heat load for cooling between both calculations runs up to 12.5MJ/m^2 (14.5%) and 14.4MJ/m^2 (14.1%) in Tokyo and Fukuoka

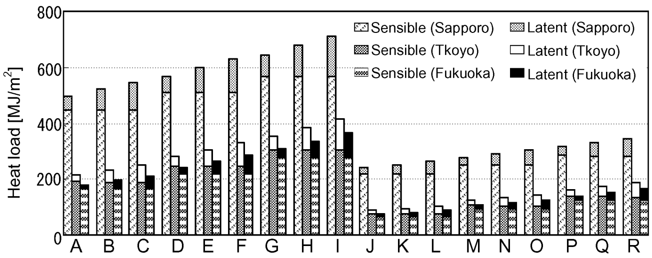


Fig. 4 Term heating load by the detailed calculation

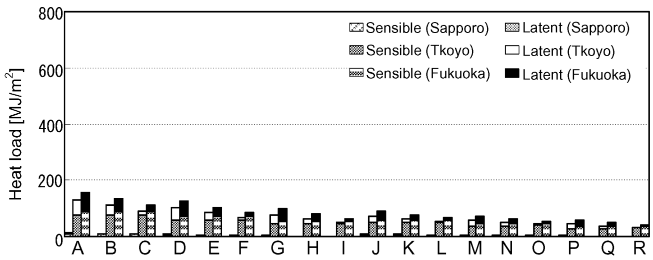
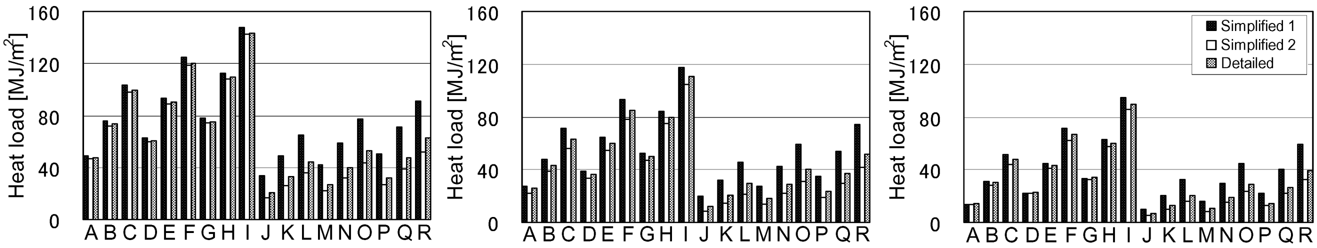
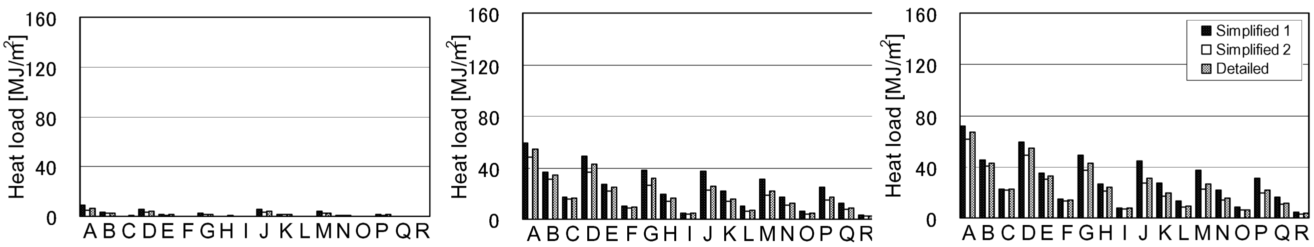


Fig. 5 Term cooling load by the detailed calculation



A) Sapporo B) Tokyo C) Fukuoka

Fig. 6 Term latent heat load for heating by the simplified and detailed calculation



A) Sapporo B) Tokyo C) Fukuoka

Fig. 7 Term latent heat load for cooling by the simplified and detailed calculation respectively

Compared with the all day and intermittent space conditioning, the calculation error of latent heat load for both heating and cooling between the simplified calculation and the detailed calculation becomes larger in the intermittent space conditioning. The error accounts to over 10% of the total heat load for both heating and cooling.

Figure 8 to 13 illustrate the hourly fluctuation of indoor temperature and humidity and the daily integrated component value of latent heat load at LDK in Tokyo for heating (January 7-8) in Case R_h and for cooling (August 7-8) in Case J_c. Compared to the simplified calculation 1 and 2 and the detailed calculation, the daily

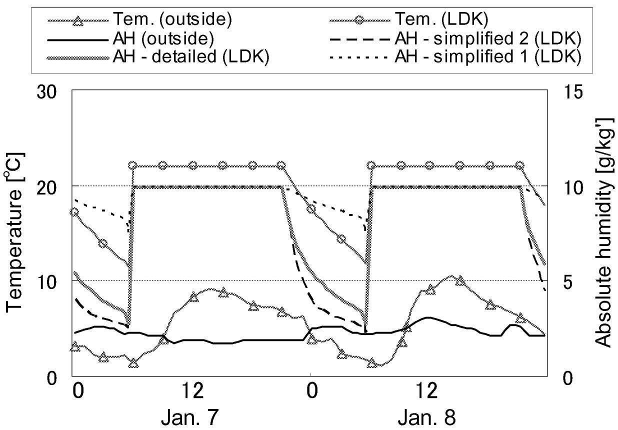


Fig.8 Temperature and humidity in LDK

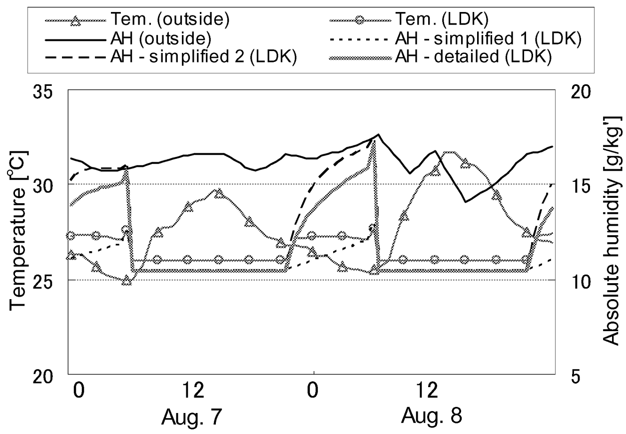


Fig.9 Temperature and humidity in LDK

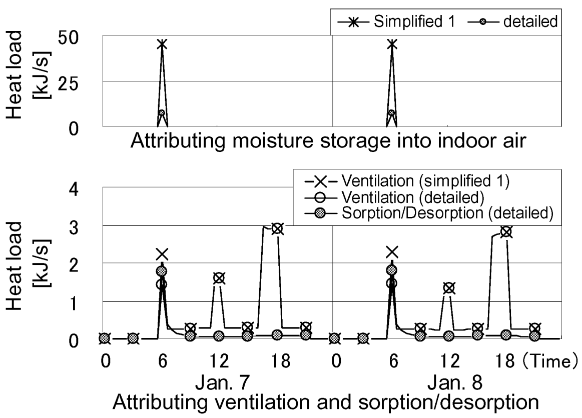


Fig.10 Component latent heat load for heating

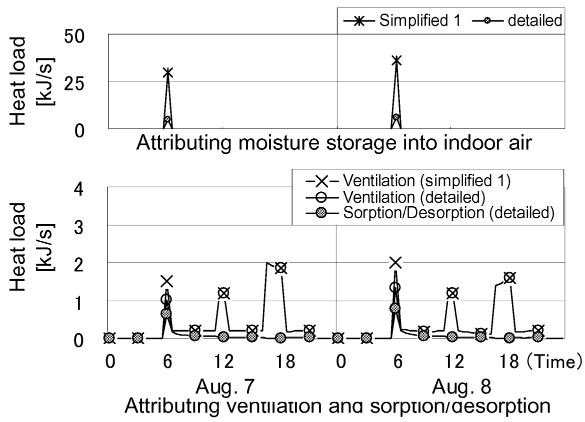


Fig.11 Component latent heat load for cooling

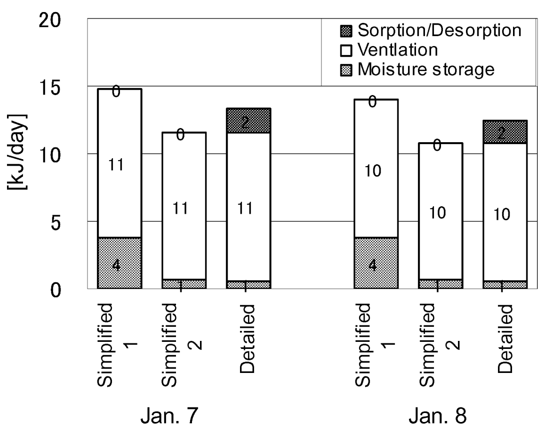


Fig.12 Integrated component value of latent heat load for heating

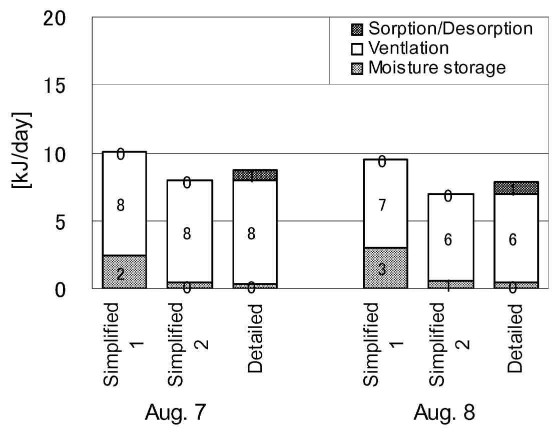


Fig.13 Integrated component value of latent heat load for cooling

integrated latent heat load becomes larger in order of the simplified calculation 1, the detailed calculation and the simplified calculation 2 the same as shown in Figure 6 and 7. The difference of term heat load between the simplified calculation 1 and 2 runs up to 32.3MJ/m^2 (43.7%) in Case R_h and 14.8MJ/m^2 (39.9%) in Case J_c. The component value of latent heat load attributing to moisture storage into indoor air of the simplified calculation 1 is quite larger than that of the simplified calculation 2. The amount of the hypothetical moisture capacity of indoor air to approximate the latent heat corresponding to moisture sorption and desorption of walls influences calculation accuracy in the simplified calculation. The latent heat load of the simplified calculation 2 which is just affected by the exact moisture storage into indoor air and ventilation becomes less than that of the detailed calculation which marks the maximum value at the start of space conditioning and decreases gradually with time. As the moisture storage in the walls at the time of no space conditioning especially impacts the latent heat load, the calculation error between the detailed and simplified calculation becomes larger in intermittent space conditioning compared to all day space conditioning.

4. CONCLUSIONS

The potential influence of moisture sorption and desorption of walls on the space conditioning load is clarified in Sapporo, Tokyo and Fukuoka, in which the climate conditions are distributed from cold to seasonally sultry, through the comparative numerical experiments utilizing the simulation software of the hygrothermal environment of whole buildings based upon detailed physical models on heat and moisture transfer and airflow. The major results obtained are listed below.

- Compared to the detailed calculation taking into account moisture transfer in wall assemblies and the conventional simplified calculation adding the hypothetical moisture capacity into the indoor air to approximate moisture sorption and desorption of walls, the calculation error of the total heat load and the latent heat load for both hating and cooling accounts for over 10% and 30% respectively. The error becomes larger in the high hygrothermal set-point for heating and in the low hygrothermal set-point for cooling. The influence of moisture sorption and desorption of walls is unable to disregard to predict the space conditioning load.
- The simplified calculation assuming the moisture capacity of indoor air is commonly used value, 16.7g/(m^3.kg/kg(DA)), estimates the latent heat load quite large. The hypothetical moisture capacity, which is the essential requirement of Housing Performance Indication Law in Japan, may be error cause although the error amount is changed by conditions of heating/cooling and building specifications.
- The latent heat load for both heating and cooling of the detailed calculation marks the maximum value at the start of space conditioning and decreases gradually with time. As the moisture is stored up into the wall assemblies at the time of natural conditions and especially impacts the latent heat load at start of space conditioning due to moisture sorption and desorption of walls, the calculation error between the detailed and simplified calculation becomes larger in intermittent space conditioning compared to all day space conditioning.

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