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Article

Human Body Exergy Balance: Numerical Analysis of an Indoor Thermal Environment of a Passive Wooden Room in Summer

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Abstract: To obtain a basic understanding of the resultant changes in the human body exergy balance (input, consumption, storage, and output) accompanying outdoor air temperature fluctuations, a "human body system and a built environmental system" coupled with numerical analysis was conducted. The built environmental system assumed a wooden room equipped with passive cooling strategies, such as thermal insulation and solar shading devices. It was found that in the daytime, the cool radiation exergy emitted by surrounding surfaces, such as walls increased the rate of human body exergy consumption, whereas the warm radiant exergy emitted by the surrounding surfaces at night decreased the rate of human body exergy consumption. The results suggested that the rates and proportions of the different components in the exergy balance equation (exergy input, consumption, storage, and output) vary according to the outdoor temperature and humidity conditions.

Keywords: passive system; wooden room; thermal comfort; human body; exergy

1. Introduction

It is important to achieve thermal comfort and energy conservation when harmoniously balancing passive (building envelope) and active (building equipment) systems [1]. Taking into account the theory of thermal adaptation [2], variations in indoor environmental conditions produced by heating and cooling systems that suit passive environmental space reasonably reflect the fluctuations of outdoor environmental conditions.

The concept of exergy includes the terms "resources" and "environment". Using this concept, it is possible to quantify the exergy consumption of energy and matter that penetrate through and diffuse into a "system" according to the current spatial temperature and humidity gradient. The environmental temperature should be set when conducting an exergy analysis and the environment is the space within which energy and matter disperse. The outdoor temperature is used as the environmental temperature in this analysis.

The exergy concept considers the sequence of generation and consumption according to natural rhythms such as annual and diurnal fluctuations. When applying the concept of exergy to the built environment, the "diffusing capacity (resources)" of energy and matter can be quantified. For example, during summer, although interior walls might retain a constant surface temperature, they emit cool radiant exergy when the outside air temperature is higher than that of the interior wall surface, such as in daytime. Conversely, warm radiant exergy is emitted from the surface of interior walls when the outside air temperature is lower than that of the interior wall surface, such as in nighttime. Thus, the character of the resource can change from "cool" to "warm" according to outside temperature variations. In addition, the quantity of the resource also changes with the temperature difference between the interior wall surface and outdoor air.

This study focused on the clarification of the mechanism of the exergy concept because it complements the energy concept, and it is applied to evaluations of thermal comfort. The discussion considers the relationship between the human body exergy balance and thermal comfort. Aspects of the exergy balance equation ("input" − "consumption" = "storage" + "output"), the character (cold, warm, dry, and wet), and the quantity of the terms in the equation change according to seasonal (spring, summer, fall, and winter) and daily (day and night) rhythms.

The outdoor temperature, which is used as the environmental temperature in the exergy balance calculation, can also be used in an adaptive model for prediction of the indoor thermal comfort temperature [3]. Therefore the possibility that the relationship between outdoor temperature and exergy may correspond to the relationship between outdoor temperature and comfort temperature should be investigated in the future. However, research on the human body exergy balance is in its early stages; for example, how the components of the human body exergy equation vary in response to the outdoor temperature and humidity conditions during both daytime and nighttime are not yet well understood.

Therefore, in this study, to obtain a basic understanding of changes in the human body exergy balance, a numerical analysis was conducted that assumed a wooden room in which passive cooling strategies such as thermal insulation and solar shading devices had been installed.

2. Exergy Balance and Thermal Comfort

Exergy is a thermodynamic concept that refers to the ability of energy and matter to disperse as a system and move toward equilibrium with the environment. In naturally-occurring processes where dispersion occurs randomly, the quantities of energy and matter are conserved, but their qualities are inevitably reduced. Therefore, an exergy analysis is useful for revealing those systems that utilize natural potential (resources). For example, when using the exergy concept to evaluate the heating and cooling systems of buildings, the evaluation considers the quality of the thermal energy that corresponds to a given temperature level. Exergy is saved when warm and cool sources are used to minimize the temperature difference between the source and outdoor air. Thus, the concept of "low-temperature heating and high-temperature cooling" uses a warm source with a relatively low temperature for heating and a cool source with a relatively high temperature for cooling. This system is also called a "low exergy system for heating and cooling" because it is achieved using only a small amount of exergy input and consumption [4].

The exergy concept may also be applied to the human body system. Some studies have investigated the relationship between the human body exergy balance and thermal comfort [5]. Humans can live comfortably when the dispersion of body heat and water is guaranteed. Therefore, thermal sensations such as "hot" and "cold" might reflect the human body exergy balance more than its energy balance [6]. A series of research projects on the relationship between the human body exergy balance and thermal comfort has revealed that the thermal environment with respect to the exergy consumption rate of the human body has a necessary minimum for thermal comfort [1]. Isawa *et al.* [7,8] conducted studies that involved numerical analyses sensitive to the human body exergy balance and revealed a heating system in harmony with the temperature regulation system of the human body. In the human body "energy" concept, there are innumerable sets of room air temperatures and mean radiant temperatures that realize the [metabolic heat] = [outgoing heat] balance. However, there is a set of room air temperatures and mean radiant temperature measurements where the exergy consumption rate is minimized while realizing the [metabolic heat] = [outgoing heat] balance. Thus, the human body "exergy" balance can complement the thermal comfort index based on the "energy" concept.

The human body exergy balance equation is derived by combining the following three elements: a human body energy balance equation, a human body entropy balance equation, and the environmental temperature (outdoor air temperature), and expressed as follows [1]:

[Warm exergy generated by metabolism] + [Warm/cool and wet/dry exergies of inhaled humid air] + [Warm and wet exergies of liquid water generated in the core by the metabolism] + [Warm/cool and wet/dry exergies of the sum of the liquid water generated in the shell by the metabolism and dry air to allow the liquid water to disperse] + [Warm/cool radiant exergy absorbed by the entire surface of the skin and clothing] − [Exergy consumption] = [Warm exergy stored in the core and shell] + [Warm and wet exergies of exhaled humid air] + [Warm/cool exergy of water vapor originating from sweat and wet/dry exergy of humid air containing evaporated water from sweat] + [Warm/cool radiant exergy discharged from the entire surface of the skin and clothing] + [Warm/cool exergy transferred by convection from the entire surface of the skin and clothing into the surrounding air]+ [External work] (1)

The first term in Equation (1) represents the "warm" exergy produced via chemical exergy consumption by various cellular activities, primarily that of muscle tissue contraction, protein composition, and the concentration differences of various minerals inside and outside the living body cells. The exergy consumption represented as the final term on the left-hand side of Equation (1) reflects two types of dispersion. The first is thermal dispersion caused by the temperature differences between the body core, whose temperature is almost constant at 37 °C, the body shell (or skin), whose temperature ranges from 30 to 35 °C, and the clothing surface, whose temperature ranges from 20 to 35 °C. The second is the dispersion of liquid water into vapor, or the free expansion of water molecules into their surrounding space. Chemical exergy consumption usually amounts to over 90% of the chemical exergy supply, which implies that the amount of entropy generated over a period of time is very large because the total amount of entropy generated is exactly proportional to the total exergy consumed. All terms, except the exergy storage on the right-hand side of Equation (1), play important roles both in the disposal of the entropy generated via the chemical exergy consumption within the human body and in the disposal of the entropy generated by thermal exergy consumption (the final term on the left-hand side of Equation (1)). These outgoing exergy flow processes, together with exergy consumption, strongly influence human well-being, health, and comfort. The sixth term on the right-hand side of Equation (1), *i.e.*, "external work" (exergy itself), is assumed zero in this study.

In the summer case studied here, it was assumed that the rate of exergy consumption by a human body of about 2.0 W/m^2 would provide thermal comfort [1]. The season for considering 2 W/m^2 as the comfortable rate is as follows. The case of natural ventilation in summer was studied in a previous research [1]. A combination of mean radiant temperature was controlled to be lower than 30 °C, e.g., in the range of 28 to 29 °C, and air movement exceeding 0.2 m/s provides the human body with its lowest exergy consumption rate, which is approximately 2 W/m^2.

3. Numerical Analysis

3.1. Calculation Method

A numerical analysis was conducted by coupling a "built environmental system" (Figure 1) with a "human body system" (Figure 2 [1]).

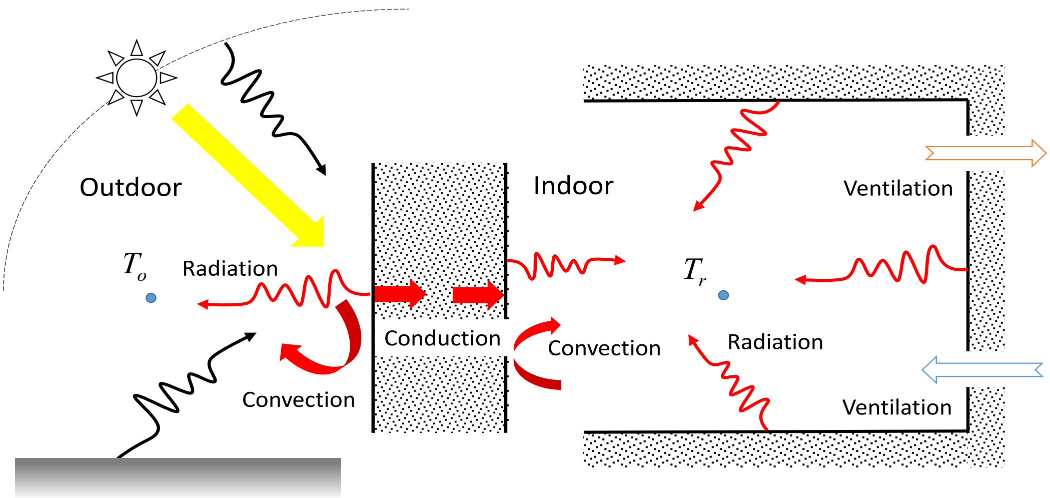

Figure 1. Built environmental system.

Here, an energy balance equation model was used that approximates the walls' heat capacity with a series of nodes for "unsteady state" conduction in the "built environmental system". Differential equations for one-dimensional heat conduction on the floor, walls, and in the room air were derived and then solved to obtain the temperatures at each point, namely, room air; interior surfaces of walls, floor, and ceiling; insides of walls, floor, and ceiling; and exterior surfaces of walls, floor, and ceiling (Appendix 1).

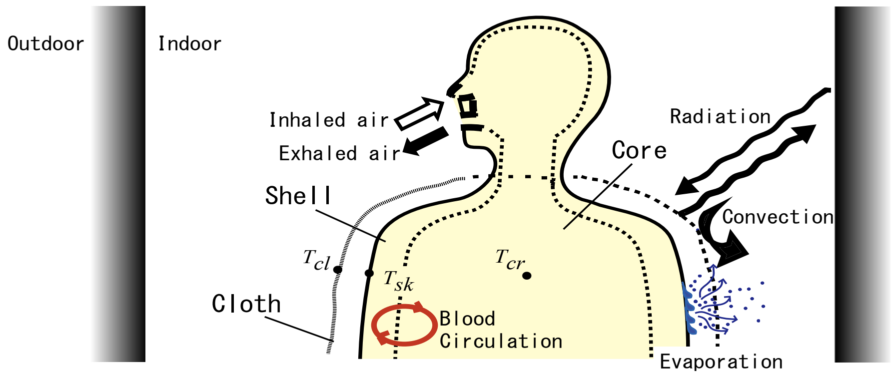

Figure 2. Human body system [1].

A human body energy balance model, or two-node model, was used for the "human body system". Body temperatures of the core, shell, and clothing were obtained by solving the two-node model, which is described in detail in [9].

Figure 3 shows the calculation flow. First, the weather data and living conditions affecting the occupant's behavior (regarding the use of natural ventilation and radiant cooling) are input into the built environmental energy balance model to obtain the temperatures of the room air and the interior surfaces of the walls. The time step used in the calculation is one hour. Second, the room air and surface wall temperatures are input into the human body energy balance model to obtain the temperatures of the core, shell, and clothing. Finally, the temperatures of the core, shell, clothing, interior air and wall surfaces of the built environment, and outdoor air (the environmental temperature necessary for the exergy calculation) are input into the human body exergy balance equation (Equation (1)).

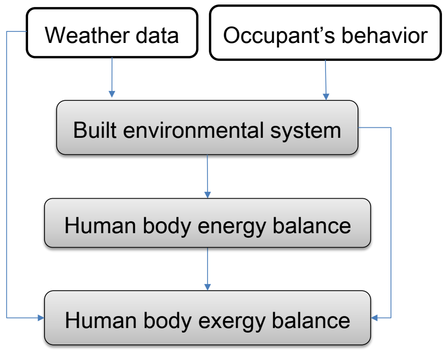

Figure 3. Calculation flow.

3.2. Fixed Condition

3.2.1. Built Environment Systems

(1) Building Envelope Specification

The wooden house is assumed to be an Itakura traditional Japanese wooden structure in which relatively thick wooden panels are used for walls (Appendix 2). The wooden room is equipped with passive cooling strategies: external solar shading devices; thermal insulation of external walls, floor, and ceiling. Furthermore, occupants are able to let outdoor air into the room by ventilation.

The built environmental space was $4 \times 3 \times 2.5$ m^3, the exterior walls (south and west) and floor of which were assumed to be in contact with the outdoor air, and the interior walls (north and east) and ceiling were assumed to be in contact with the indoor air. A 2×1.6 m^2 double glazed window (each pane 6-mm-thick with a total heat transfer coefficient of air space of 8.5 W/m^2·K) was located in the south-facing exterior wall. The incident solar radiation on the glass window was multiplied by a factor of 0.35 to configure the external shading devices. The finishing material of the floor, ceiling, and walls (both exterior and interior) was 30-mm natural wood sheet. For thermal insulation, wool-based insulation material (100-mm thick) was installed against the exterior wall and under the floor.

(2) Weather Conditions

The standard year weather data for Tokyo were used [10]. The pre-calculation period was 10 days, and the results were evaluated for five days in summer (1–5 August).

(3) Occupant Behavior Conditions

Two aspects, the use of radiant cooling and opening of windows for ventilation, are considered to be the occupant behavior in this study. Radiant cooling is assumed to operate on a continuous basis in this study.

The heat generation schedule in the room space was assumed to follow standard conditions (from the Institute for Building Environment and Energy Conservation) [11] (Appendix 3). The proportions of generated heat were 60% radiation and 40% convection.

3.2.2. Human Body System

The human body was assumed located in the center of the room, adopting a sedentary posture and wearing summer clothes of 0.43 clo with a metabolic rate of 1.1 met. The relative humidity of the room air was equal to that outdoors.

3.3. Variable Condition

Physiological adaptations are taken into account in the human body temperature calculation (two-node model). Behavioral adaptations are included as the comparative (variable) condition of the calculation: the use of radiant cooling and opening of windows for ventilation.

Table 1 presents the comparative conditions of the three trial cases. Case 1 is an open room with no radiant cooling, Case 2 is an open room with radiant cooling, and Case 3 is a sealed room with radiant cooling. The number of air changes and air velocity were set at 15 times/h and 0.3 m/s to model natural ventilation in the open room [12] and 0.5 times/h and 0.1 m/s to model minimal mechanical ventilation in the sealed room. Removal heat by radiation was set to be 0 W for absence of radiant cooling and 400 W with radiant cooling. Radiant cooling was defined as the temperature at which condensation did not occur.

Table 1. Comparison of conditions.

Comparative Element	Case 1: Open Room With No Radiant Cooling	Case 2: Open Room With Radiant Cooling	Case 3: Sealed Room With Radiant Cooling
Number of air changes	15 times/h	15 times/h	0.5 times/h
Air velocity	0.3 m/s	0.3 m/s	0.1 m/s
Removal of heat by radiation	0 W	400 W	400 W

4. Results and Discussion

Figures 4 and 5 show the variations of room air temperature and mean radiant temperature, respectively, with time. In Case 1 (Figure 5), the mean radiant temperature is higher than the outdoor temperature because the internal heat generated could not be discharged adequately. In Case 2 (Figure 5), although there is a period during which the mean radiant temperature is >30 °C, it is generally lower than the outdoor air temperature because of the effects of radiant cooling. In Case 3, (Figure 5), the mean radiant temperature is ≤30 °C because only a little outdoor air was introduced.

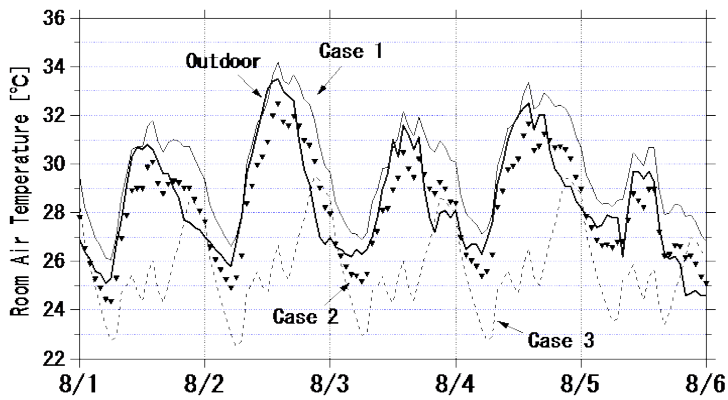

Figure 4. Room air temperature.

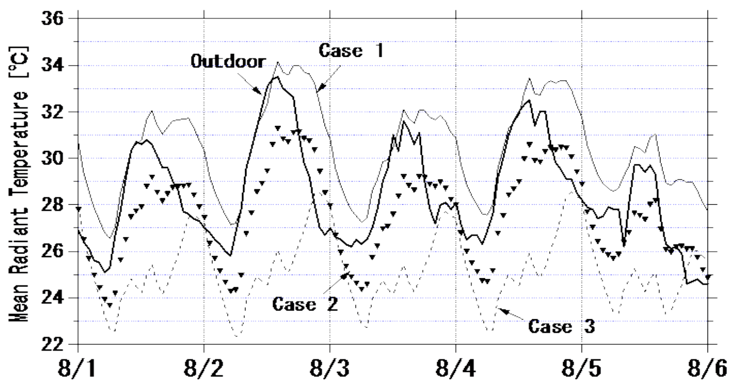

Figure 5. Mean radiant temperature.

Figure 6 shows the human body exergy consumption rate. Comparing the ranges of fluctuation shows that the largest is for Case 1 (1.5–2.7 W/m^2), followed by Case 2 (1.6–2.6 W/m^2), and Case 3 (1.1–2.4 W/m^2). The period during which the exergy consumption rate is >2.0 W/m^2 (which is comfortable) can be seen in the daytime for Case 1 and in the morning for Case 3. If Figures 4–6 are taken into consideration, the human body would experience thermal stress in Cases 1 and 3, because of the insufficient discharge of exhaust heat in Case 1 and excessive cooling in Case 3.

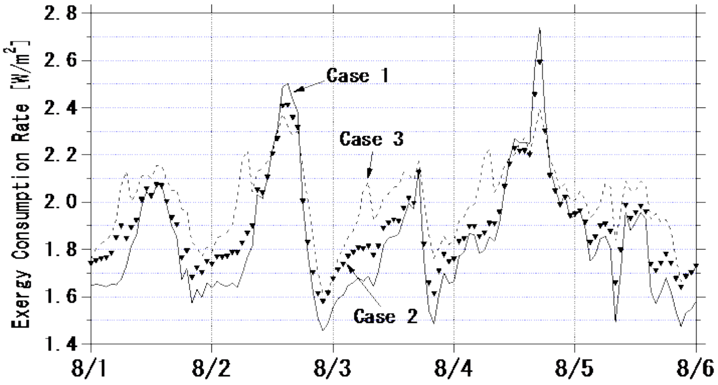

Figure 6. Human body exergy consumption rate.

Figures 7 and 8 show the cool and warm radiant exergy rate, respectively, input into a human body from an interior surface. In Figure 5, when the mean radiant temperature is lower than the outdoor air temperature (environmental temperature), cool radiant exergy is emitted, and warm radiant exergy is emitted in the converse situation. Figure 7 shows that when the outside air temperature rises in the daytime, cool radiant exergy is emitted in descending order of magnitude for Cases 3, 2, and 1. Figure 8 shows that when the outdoor air temperature falls in the evening, night, and morning, warm radiant exergy is emitted in descending order of magnitude for Cases 1, 2, and 3.

In the daytime, the human body exergy consumption rate increases in Case 3, (Figure 6), which is in general agreement with the peak of the cool radiant exergy rate of Case 3 (Figure 7). Conversely, in the nighttime, the human body exergy consumption rate decreases in Case 1 (Figure 6), which is in general agreement with the peak of the warm radiant exergy rate of Case 1 (Figure 8). From these results, it can be concluded that the cool radiant exergy of daytime increases the rate of human body exergy consumption, and the warm radiant exergy at night decreases the rate of human body exergy consumption. The value of the cool radiant exergy is 200–300 mW/m^2 during the period when the human body exergy consumption rate in Case 3 becomes about 2.0 W/m^2, which is still comfortable.

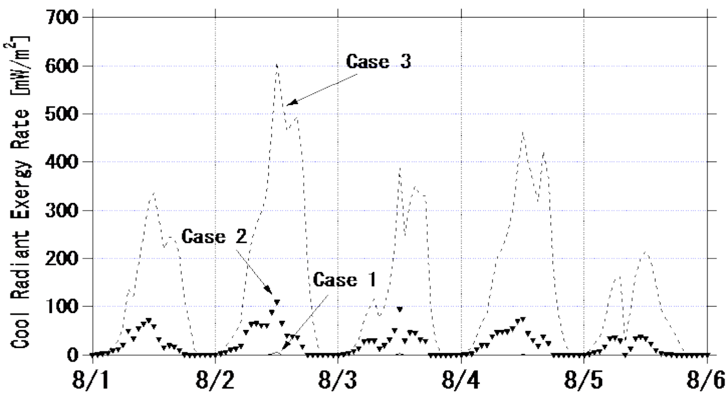

Figure 7. Cool radiant exergy input rate.

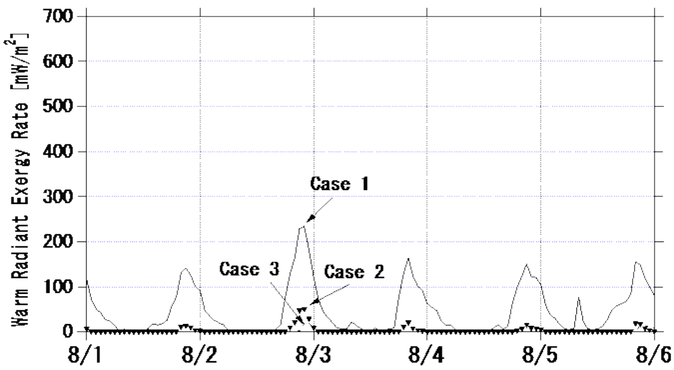

Figure 8. Warm radiant exergy input rate.

This suggests that the combination of moderate radiant cooling and natural ventilation is well suited to the wooden room equipped with passive cooling strategies for control of the indoor thermal environment such as solar control by external shading devices over glass windows and thermal insulation of the building envelope.

Figure 9 shows the elements of the human body exergy balance ("input" − "consumption" = "stored" + "output") in daytime. Figure 9 shows a time of 12:00 Local Time on August 2, when the value of the cool radiant exergy was the largest in Case 3 (Figure 7). In Figure 9, the values for "metabolism + shivering," "water generated by metabolism (shell)," and "consumption" are comparatively large in all three cases. The large value for "metabolism + shivering" is resultant from the temperature difference between the core and outdoor air. The large value for "water generated by metabolism (shell)" is resultant from the humidity differences between water from sweat (sensitive and insensitive) and the outdoor air. Most exergy consumption is via "metabolism + shivering" and "water generated by metabolism (shell)". The values of "metabolism + shivering" for the three cases in descending order of magnitude are Cases 1, 2, and 3. This corresponds to the order of high core temperature in the three cases. The values of "water generated by metabolism (shell)" for the three cases in descending order of magnitude are Cases 1, 2, and 3. This corresponds to the order for large amounts of perspiration. In Case 3, cool radiant exergy is emitted from the human body because cool radiant exergy is input from both sides, *i.e.*, radiation and convection. The role of the cooling system is to allow warm exergy to be discarded at a moderate rate from the human body [1], because excessive cool exergy was input into the human body in Case 3. Comparing the output term of "the moist air vaporized" in all three cases shows the value in Case 3 is comparatively large. This is because the temperature of the dry air, which performs counter diffusion to the streaming sweat, will hold cool exergy in the outdoor air, compared with the other cases.

Figure 10 shows the elements of the human body exergy balance ("input" − "consumption" = "stored" + "output") in night time. Figure 10 shows a time of 22:00 Local Time on August 2, when the value of the warm radiant exergy was the largest in Case 1 (Figure 8). The values of "metabolism + shivering" and "consumption" are comparatively large in all three cases. In Figure 10, the value of "the water generated by metabolism (shell)," which was comparatively large in Figure 9, is small. This is because the room air temperature drops with the fall in outdoor air temperature at night; hence, the amount of perspiration by the human body decreases. The value of "metabolism + shivering" is about 2 W/m^2 in Figure 10 (night) and about 0.8 W/m^2 in Figure 9 (daytime). The reason for the comparatively large nighttime value is that the temperature difference between the core and outdoor air increases as the outdoor temperature falls at night. In all cases, warm radiant exergy is input, and warm radiant exergy and warm convective exergy are output from the human body. The reason that all terms become warm exergy is that the room air and wall surface temperatures are higher than the outdoor air temperature at nighttime. With respect to the radiation in Case 1, both the warm radiant exergy input and output are large compared with the other two cases. Room air temperature and mean radiant temperature at this time are 30.7 and 32.3 °C (Figures 4 and 5), respectively, and, as the environment is hot (>30 °C), it can be inferred that this could be uncomfortable. In the "consumption" element of Figure 10, the exergy consumption rate of Case 1 is relatively small compared with the other two cases. If the above factors are considered, it can be concluded that some amount of excessive warm exergy was input such that the shell and core temperatures were maintained comparatively high; hence, the consumption was somewhat retarded as a result and a comparatively large warm exergy value was output. Generally, a smaller human body exergy consumption rate is good. However, a low consumption rate, wherein the minimum consumption required for a human body is not attained, does occasionally occur because the temperature difference between the core and the shell can become small in an environment with high temperature and humidity.

As shown in Figures 6–10, aspects of the human body exergy balance change with fluctuations of the outdoor air temperature and humidity conditions. It is suggested that some moderate rates of exergy input, consumption, storage, and output correspond to the environmental conditions. Hence, this balance may be related to physiological adaptation: this should be investigated in future studies.

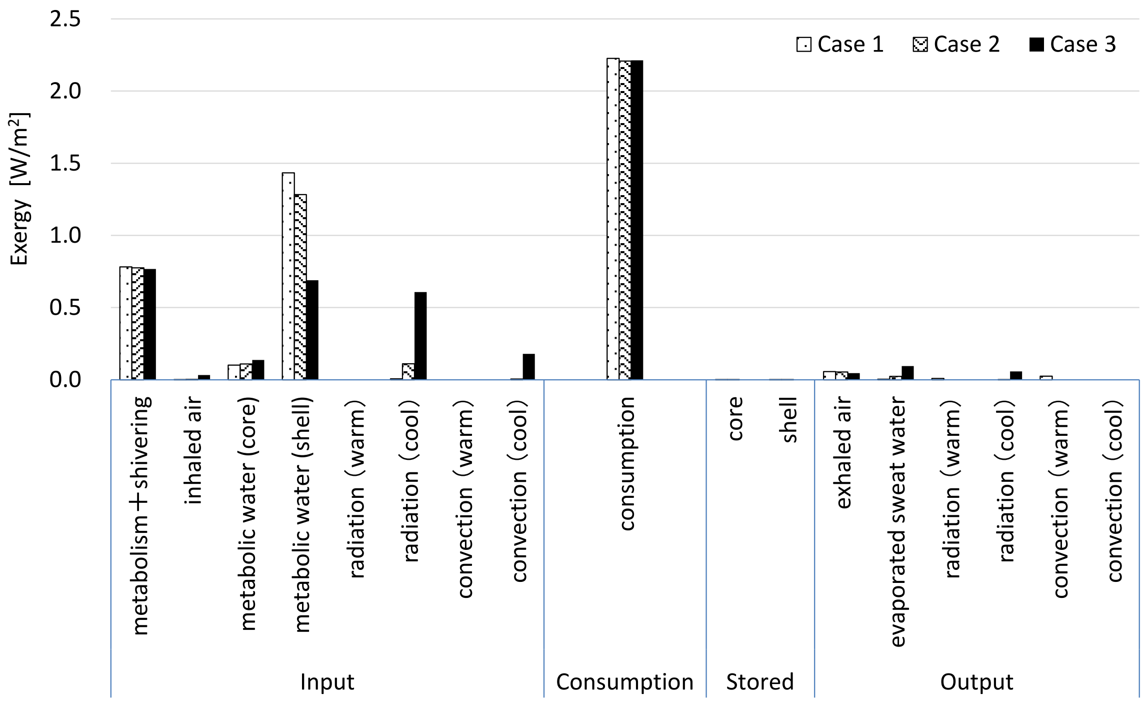

Figure 9. Elements of the human body exergy balance (August 2; 12:00 Local Time).

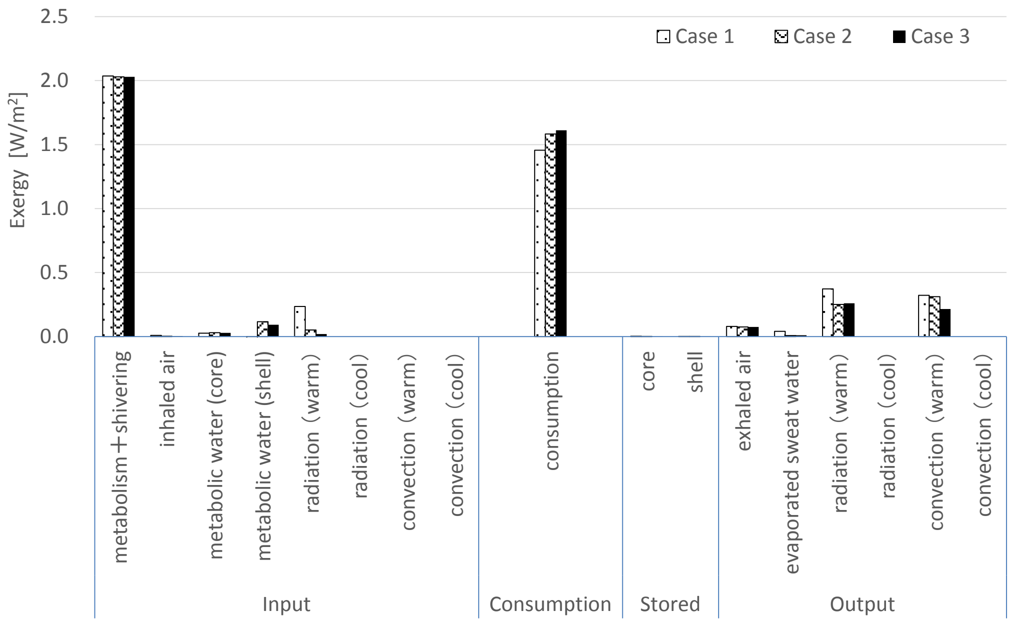

Figure 10. Elements of the human body exergy balance (August 2; 22:00 Local Time).

5. Conclusions and Further Work

To acquire fundamental knowledge regarding changes in the components of the human body exergy balance, a numerical analysis was conducted for a wooden room, in which passive cooling strategies had been installed, such as suitable solar shading devices and thermal insulation, during the summer season.

The results suggested that the rates and proportions of the different components in the exergy balance equation (exergy input, consumption, storage, and output) vary according to the outdoor temperature and humidity conditions.

It was determined that low-exergy consumption alone is not an adequate indication of thermal comfort and is not always ideal. Additional requirements may be the outdoor temperature and humidity conditions at each time (which is similar to the adaptive comfort temperature). The relationship between human body exergy balance components including consumption rate and comfort temperature should be investigated as part of further work.

Whether the human body exergy balance can be used to indicate the thermal comfort provided by passive strategies also should be investigated in future work. If this can be developed as an adequate indicator, passive design may become more accepted in many buildings. To facilitate this purpose, possibly future studies should consider the use of meteorological data, obtained at 1 min intervals, to perform quantitative investigations of exergy resulting from the adaptations (physiological and behavioral) that arise from daily (daytime and night) or seasonal (spring, summer, autumn, and winter) rhythms.

Acknowledgments

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Conflicts of Interest

The author declares no conflict of interest.

Appendix

Appendix 1

The room calculation model used in this study followed reference [1] (Figure A1). First, the wall heat capacity is approximated by a series of nodes as shown in Figure above. Node i is surrounded by node $(i - 1)$ and node $(i + 1)$. Their temperatures are denoted by T_i, T_{i-1}, and T_{i+1}, respectively. The diagram containing the symbols of closed circles with corrugated lines represents the whole of the thermal conduction within wall. The closed circles represent the nodes with heat capacity and the corrugated lines denote the thermal resistance of conduction, which is equal to the reciprocal of thermal conductance. The nodes representing the exterior and interior surfaces are denoted by open circles. The node representing the exterior surface is connected with all the opposite surfaces that emit thermal radiation to the exterior surface of the wall and also with the outdoor air for convective heat transfer. The opposite surface outdoors and outdoor air are represented by open squares. The same applies to the interior surface, which is connected with the opposite surfaces indoors and with the indoor air.

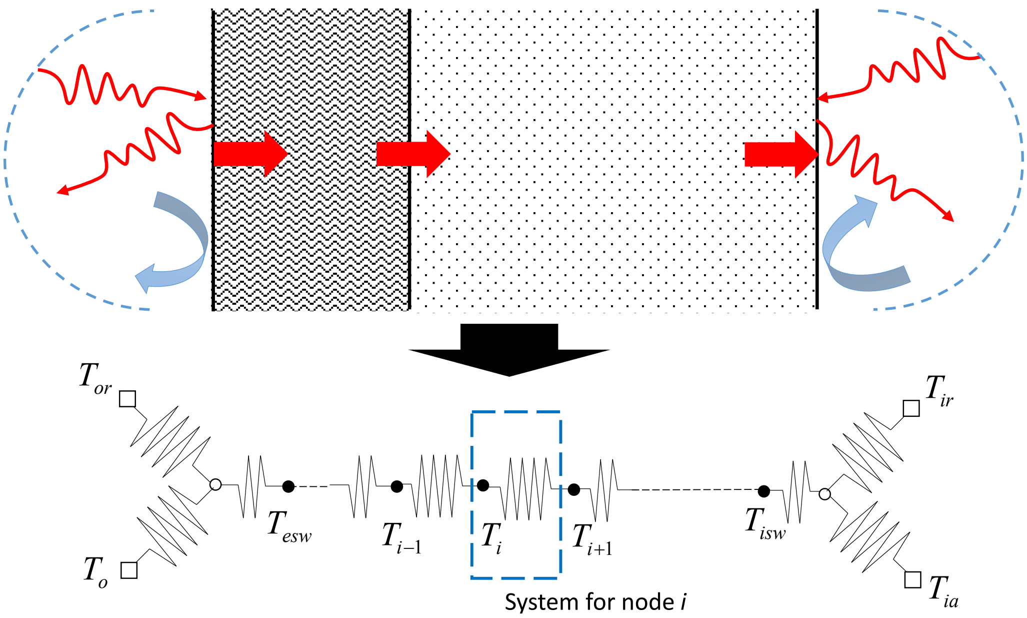

Figure A1. Model and equation of built environmental system [1].

The energy balance equation for node i can be expressed as follows:
[Energy input] = [Energy stored] + [Energy output]

$$_{-}q_i dt = c_{pi}\rho_i l_i dT_i + {}_{+}q_i dt \tag{A1}$$

where:

$$_{-}q_i = {}_{-}C_i\left(T_{i-1} - T_i\right) \tag{A2}$$

$$_{+}q_i = {}_{+}C_i\left(T_i - T_{i+1}\right) \tag{A3}$$

The symbols used are as follows: $_{-}q_i$ is the thermal energy flow rate by conduction from node $(i - 1)$ to node i, and $_{+}q_i$ is that from node i to node $(i + 1)$. The unit is W/m^2. The symbol t denotes time (unit: seconds and dt denotes) an infinitesimally short period of time. The symbol dT_i denotes an infinitesimally small increase in temperature at node i (unit: Kelvin). The symbols $_{-}C_i$ and $_{+}C_i$ are the thermal conductance between nodes (i – 1) and i and between i and (i + 1), respectively, with unit W/(m^2·K). c_{pi} is the specific heat capacity of node i, with unit J/(kg·K), ρ_i is the density of material represented by node i, unit kg/m^3, and li is the thickness of material represented by node i, unit meters.

The "implicit" type of equations were used for numerical calculation in this study. "Implicit"-type equations set up for respective nodes are dependent on each other, so these equations have to be solved simultaneously by calculating the inverse matrix together with the product of vector and matrix, but there are no constraints with respect to the sizes of space-wise and time-wise finite differences.

Appendix 2

Table A2. Data of the building envelope specification.

Site		Material (from Outdoors to Indoors)	Thickness (mm)	Heat Conductivity W/(m^2 (K/m))	Specific Heat Capacity J/(kg K)	Density (kg/m^3)
South Window	1	Glass	6	0.78	770	2540
	2	air space	6	8.5	1	1.2
	3	Glass	6	0.78	770	2540
South External Wall	1	sheet steel	0.4	45	480	7860
	2	plasterboard	12.5	0.14	1130	1000
	3	non-sealing air space	24	14.5	1	1.2
	4	Wool (heat insulation material)	100	0.04	1400	28
	5	plasterboard	12.5	0.14	1130	1000
West External Wall	1	sheet steel	0.4	45	480	7860
	2	plasterboard	12.5	0.14	1130	1000
	3	non-sealing air space	24	14.5	1	1.2
	4	Wool (heat insulation material)	100	0.04	1400	28
	5	plasterboard	12.5	0.14	1130	1000
North Interior wall	1	plasterboard	12.5	0.14	1130	1000
	2	non-sealing air space	120	14.5	1	1.2
	3	plasterboard	12.5	0.14	1130	1000
East Interior Wall	1	plasterboard	12.5	0.14	1130	1000
	2	non-sealing air space	120	14.5	1	1.2
	3	plasterboard	12.5	0.14	1130	1000
Ceiling	1	Wood flooring	15	0.14	1300	500
	2	Plywood	15	0.15	1300	500
	3	non-sealing air space	400	14.5	1	1.2
	4	Plywood	15	0.15	1300	500
Floor	1	Glass wool (20 K)	105	0.041	840	20
	2	plywood	12	0.15	1300	550
	3	Wood flooring	15	0.14	1300	500

Appendix 3

Table A3. Schedule of internal heat generation (Unit: W).

Generation Source	Time																							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Staying in the room *	–	–	–	–	–	–	100	200	100	100	–	–	100	100	–	–	100	200	200	300	300	200	100	100
Lighting equipment	–	–	–	–	–	–	22.6	97.5	52.5	115.0	17.5	–	67.5	52.5	–	–	35.1	70.0	70.0	80.0	120.0	70.0	70.0	35.1
Device sensible heat	6.9	6.9	6.9	6.9	6.9	6.9	6.9	209.1	210.6	107.8	57.4	6.9	107.8	158.7	6.9	6.9	107.8	158.7	209.1	209.1	209.1	209.1	182.9	182.9
Sum total	7	7	7	7	7	7	130	507	363	323	75	7	275	311	7	7	243	429	479	589	629	479	353	318

Note: * Conditioned room space is 0.083 to 0.25 person per square meter.

Appendix 4

Example Regarding the Involvement between Exergy and Physical Sensation [1]: For this example, "A" is set as the case where 20 L of water is raised from 20 °C to 40 °C and "B" is the case where 5 L of water is raised from 20 °C to 100 °C. Here "A" is warm and "B" very hot; therefore, the difference between them is very clear. In the energy evaluation, "A" and "B" are calculated to be 1647 kJ; thus, both values are identical. Clearly, the energy evaluation is inconsistent with the physical sensation. In contrast, in the exergy evaluation, "A" is calculated to be 55 kJ and "B" 194 kJ; thus, the value of "B" is 3.5 times larger than "A". These values are consistent with the physical sensations involved.

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