DEVELOPMENT OF EVALUATION METHOD FOR ENERGY BALANCING SYSTEM IN SUPER-LARGE COMPLEX BUILDINGS

Dae Uk Shin[1], Seung Jae Lee[1], Goo Sang Joe[1], So Jeong Park[1], Myoung Souk Yeo[2] and Kwang Woo Kim[2,*]

[1] Department of Architecture and Architectural Engineering, Graduate School of Seoul National University, Seoul (Korea)

[2] Department of Architecture and Architectural Engineering, Seoul National University, Seoul (Korea)

* Corresponding author. Address: Department of Architecture and Architectural Engineering, Seoul National University, Shinlim-Dong, Kwanak-Gu, Seoul 151-744, Republic of Korea. Tel.: +82 2 880 7065; fax: +82 2 871 5518; E-mail: snukkw@snu.ac.kr

1. Introduction

Currently, the numbers of super-large complex buildings, which have not only rooms requiring heating but also rooms requiring a cooling load, have increased. Therefore, the applicability of a Balanced Heat Recovery concept (ASHRAE, 2008) in which the system works year-round to recover of all the internal heat before adding external heat, is increasing. By utilizing this type of system, it is possible to maintain a set temperature by supplying small amount of energy into the system. In earlier research, Choi (1995) and Choi et al. (2008) performed similar study for resident buildings and demonstrated the importance of renewable the internal heat energy, and Chen et al. (2011) demonstrated that the heat exchange network synthesis, which is applied in industrial field commonly, can be applied for large public buildings.

The Energy Balancing System has been being developed inspired by the Balanced Heat Recovery. As the zone heating and cooling load are mainly related when energy balancing, this system have advantages in cases in which the ratio of the zone heating load and the zone cooling load and their time of occurrence are similar. This becomes clearer if the system is evaluated quantitatively. When evaluating the efficiency of the conventional HVAC system, the efficiency of plant can be the criteria affected by profile of heat source. However, the efficiency of the Energy Balancing System is affected by the zone load ratio, therefore, it is necessary to determine the different criteria not the efficiency of plant. As the different criteria should be determined, the evaluation method should be also developed.

In this paper, several processes are used to develop an evaluation method for the Energy Balancing System. After defining the Energy Balancing System, the criteria for evaluating and the significant factors to be considered when evaluating will be determined firstly. Then the calculation process for criteria will be defined and the equations for the process will then be developed. Finally, the impact of the significant factors will be analyzed by a simulation.

2. Energy Balancing System

The Energy Balancing System consists of the water tanks to supply stable heat medium temperature for heating, cooling and domestic hot water and store the waste water and the water-to-water heat pumps not only to balance energy in low temperature and high temperature source, but also to recover heat from low temperature source to high temperature sink. In hot water tank and chilled water tank, there are two types of water; “the available water” and “the unavailable water” for heating or cooling. In the available water, there is “available energy(E_{A})” for heating or cooling. In unavailable water, there is “unavailable energy(E_{UA})” for heating or cooling which is cold heat(in a hot water tank) or hot heat(in a chilled water tank) energy gained when heating or cooling. E_{UA} can be the potential energy for other side; E_{UA} in hot water tank can be used for cooling and that in chilled water tank can be used for heating. Therefore, E_{UA} is defined as “transformable energy(E_{T})” for this system.

The Energy Balancing System was developed to convert the transformable energy in the chilled water tank$\left(E_{\mathrm{C,T}}\right)$ to the available energy for heating in the hot water tank$\left(E_{\mathrm{H,A}}\right)$ and convert the transformable energy in the hot water tank$\left(E_{\mathrm{H,T}}\right)$ to the available energy for cooling in chilled water tank$\left(E_{\mathrm{C,A}}\right)$ through balancing two of transformable energies. The temperature of water which has $\mathrm{E_{C,T}}$ should be lower to be the water which has $\mathrm{E_{C,A}}$ and that of water which has $\mathrm{E_{H,T}}$ should be higher to be the water which has $\mathrm{E}_{H,\mathrm{A}}$. Therefore, $E_{\mathrm{C,T}}$ is higher than 0 and $E_{\mathrm{H,T}}$ is lower than 0, and these can become the available energy by balancing [Fig. 1].

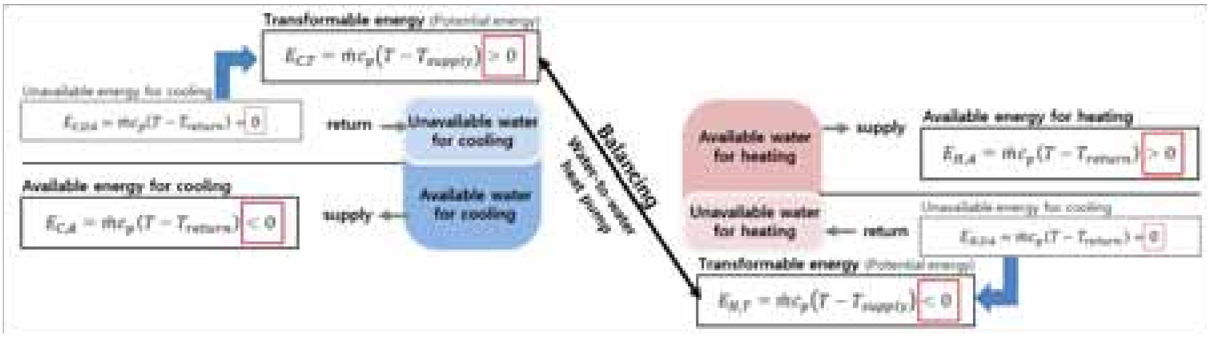

Fig. 1: Concept diagram of the Energy Balancing System

In addition, it is possible to recover waste heat from waste water to available energy for zone heating and domestic hot water and recover $E_{C,T}$ to available energy for domestic hot water by this system.

3. Evaluation method for Energy Balancing System

3.1 Criteria and significant factors

As the Energy Balancing System serves to balance the transformable energies from cooling and heating to convert them to available energies for heating and cooling, if the amount of the heating and cooling load which can be offset by energy balancing is relatively large, the amount of energy input will be relatively small. Therefore, the percentage of load offset by balancing(r_{Bal}) can serve as the criteria for evaluating the Energy Balancing System.

When evaluating the Energy Balancing System, the zone load($Q_{Zone,t}$) can be the most significant factor as mentioned earlier. In addition to $Q_{Zone,t}$, another two significant factors were determined as shown below.

1) When offsetting each load by balancing, it will be effective if the amount and the occurrence time of the heating and cooling load are similar because almost of both transformable energies($E_{\mathrm{H,T}}$, $E_{\mathrm{C,T}}$) can be balanced. However, if the amount and occurrence time of these two factors are very different, the amount of balancing is lower. In a real situation, it is difficult to find a case in which the amount and the occurrence time of the heating and cooling load are similar. Therefore, it is necessary to consider the storage capacity of the tank (E_{Cap}) to store $E_{\mathrm{H,T}}$ and $E_{\mathrm{C,T}}$ of the current timestep to balance at a later timestep.

2) When balancing $E_{H,T}$ and $E_{C,T}$, the available energy for heating gained by balancing ($E_{H,A,Bal}$) is larger than the available energy for cooling gained by balancing($E_{C,A,Bal}$) because the amount of energy input(E_{input}) is added to $E_{C,A,Bal}$ when $E_{H,A,Bal}$ is formed. Therefore, it is necessary to consider the balancing ratio (r_{HC}). $\mathrm{r_{HC}}$ can be derived as shown below.

   - $E_{H,A,Bal}$ is equal to the sum of $E_{C,A,Bal}$ and E_{input}(eq 1).

     $$E_{H,A,Bal} = E_{C,A,Bal} + E_{input} \quad \text{(eq. 1)}$$

   - As $\mathrm{E_{input}}$ can be expressed using the cooling COP ($\mathrm{COP_C}$) and $\mathrm{E_{C,A,Bal}}$(eq. 2), the equation for $\mathrm{E_{H,A,Bal}}$ can be determined by (eq. 3).

     $$E_{input} = \frac{E_{C,A,Bal}}{COP_C} \quad \text{(eq. 2)}$$

     $$E_{H,A,Bal} = E_{C,A,Bal} + \frac{E_{C,A,Bal}}{COP_C} = E_{C,A,Bal}\left(1 + \frac{1}{COP_C}\right) \quad \text{(eq. 3)}$$

   - Therefore, the balancing ratio (r_{HC}) is derived by (eq. 4).

     $$r_{HC} = \frac{E_{H,A,Bal}}{E_{C,A,Bal}} = 1 + \frac{1}{COP_C} \quad \text{(eq. 4)}$$

3.2 Calculation Process

To calculate the percentage of zone load offset by balancing (r_{Bal}) as criteria, the total zone load($Q_{Zone,tot}$) and the total zone load offset by balancing($Q_{LO,Bal,tot}$) must be derived.

$Q_{Zone,\text{tot}}$ can be calculated by sum of the zone load($Q_{Zone,t}$) in all timesteps. $Q_{\text{LO,Bal,tot}}$ is related the available energy gained by balancing($E_{A,Bal,t}$) *i*n all timesteps. $Q_{Zone,t}$ can be decided by measuring or by simulation. Therefore, $E_{A,Bal,t}$ must be derived.

To derive $E_{A,Bal,t}$, the remaining transformable energy after offsetting the load($E_{T,AO,t}$), which can be used during the balancing process, should be determined. $E_{T,AO,t}$ can be the sum of the initial transformable energy of the current timestep($E_{T,I,t}$) (which is equal to the final transformable energy of the former timestep($E_{T,F,t-1}$) and the load offset by the available energy($Q_{LO,A,t}$) as E_T is formed when offsetting the load by the available energy. $Q_{LO,A,t}$ is related to $Q_{Zone,\text{t}}$ and the initial available energy($E_{A,I,t}$) because this value varies depending on whether $E_{A,I,t}$ (which is equal to the final available energy of former timestep($E_{A,F,t-1}$)) is larger than $Q_{Zone,t}$ or not. The amount of the load which cannot be offset by $E_{A,I,t}$ can be the load offset by auxiliary equipment($Q_{LO,Aux,t}$). Therefore, $E_{A,F,t}$ and $E_{T,F,t}$ must be derived.

$Q_{A,F,t}$ is the sum of the remaining available energy after offsetting the load($E_{A,AO,t}$) and $E_{Bal,t}$, and $E_{A,AO,t}$ is related to the $E_{A,I,t}$ and $Q_{LO,A,t}$. $E_{T,F,t}$ is the value of $E_{Bal,t}$ subtracted from $E_{T,AO,t}$, and $E_{T,AO,t}$ related to $E_{T,I,t}$ and $Q_{LO,A,t}$.

Finally, the calculation process for the percentage of zone load offset by balancing(r_{Bal}) is determined. Process 1 to 6 should be performed at every timesteps, and processes 7 and 8 should be performed once after last timestep [Tab. 1].

Tab. 1: Calculation process for the percentage of load offset by balancing

Calculation process		Symbol
1) Input the 'zone load'		$Q_{Zone,t}$
2) Calculate the 'initial available and transformable energy of the current timestep'	2-1) Available energy	$E_{A,I,t}$
	2-2) Transformable energy	$E_{T,I,t}$
3) Calculate the 'load offset by available energy or auxiliary equipment'	3-1) Load offset by available energy	$Q_{LO,A,t}$
	3-2) Load offset by auxiliary equipment	$Q_{LO,Aux,t}$
4) Calculate the 'remaining available and transformable energy after offsetting load'	4-1) Available energy	$E_{A,AO,t}$
	4-2) Transformable energy	$E_{T,AO,t}$
5) Calculate the 'available energy gained by balancing'		$E_{A,Bal,t}$
6) Calculate the 'final available and transformable energy of the current timestep'	6-1) Available energy	$E_{A,F,t}$
	6-2) Transformable energy	$E_{T,F,t}$
7) Calculate the 'factors for deriving percentage of load offset by balancing'	7-1) Total zone load	$Q_{Zone,tot}$
	7-2) Total zone load offset by balancing	$Q_{LO,Bal,tot}$
8) Derive the 'Percentage of zone load offset by balancing'		r_{Bal}

3.3 Equations for process

An eight-step process was developed to calculate the percentage of zone load offset by balancing(r_{Bal}). In this section, the equations for each step will be determined.

1) Input the zone load($E_{Zone,\mathrm{t}}$)

The heating load($E_{H,Zone,\mathrm{t}}$) and the cooling load($E_{C,Zone,\mathrm{t}}$) of the zone derived by simulation or by a measuring method are inputted.

2) Calculate the initial available and transformable energy of current timestep

2-1) Available energy($E_{A,I,t}$)

The initial available energy for heating($E_{H,A,I,t}$) and the available energy for cooling($E_{C,A,I,t}$) of current timestep are supposed to be equal to the final available energy($E_{A,F,t}$) of the former timestep (pro. 6-1). The initial value can be a random value with a range smaller than the E_{Cap}.

$$E_{H,A,I,t} = E_{H,A,F,t-1} \quad \text{(eq. 5)}$$

$$E_{C,A,I,t} = E_{C,A,F,t-1} \quad \text{(eq. 6)}$$

2-2) Transformable energy($E_{T,I,t}$)

The initial transformable energy in hot tank($E_{H,T,I,t}$) and the initial transformable energy in chilled water tank ($E_{C,T,I,t}$) of current timestep are supposed to be equal to the final transformable energies($E_{T,\mathrm{F},t}$) of the former timestep (pro. 6-2). The initial value is derived by subtracting the initial value of the initial transformable energy of the current timestep from the storage capacity of tank(E_{Cap}).

$$E_{H,T,I,t} = E_{H,T,F,t-1} \quad \text{(eq. 7)}$$

$$E_{C,T,I,t} = E_{C,T,F,t-1} \quad \text{(eq. 8)}$$

3) Calculate the load offset by available energy or auxiliary equipment

3-1) Load offset by available energy($Q_{LO,A,t}$)

When the initial available energy($Q_{A,I,t}$) is equal to or greater than the zone load($Q_{Zone,t}$), all of $Q_{\mathrm{Zone},t}$can be offset by $E_{A,I,t}$. In this case, $E_{A,I,t}$ is equal to $Q_{Zone,t}$. However, when the $E_{A,I,t}$ is smaller than $Q_{Zone,t}$, part of $Q_{Zone,t}$ can be offset by $Q_{A,I,t}$ and the remained $Q_{Zone,t}$ should be offset by auxiliary equipment. In this case, $Q_{A,I,t}$ is equal to the smaller value of $Q_{Zone,t}$ or $Q_{A,I,t}$. Therefore, the smaller value between the $Q_{Zone,t}$ and $E_{\mathrm{A,I},t}$ is calculated to derive the heating load($Q_{H,LO,A,t}$) and the cooling load offset by available energy($Q_{C,LO,A,t}$)

$$Q_{H,LO,A,t} = MIN(Q_{H,Zone,t}, E_{H,A,I,t}) \quad \text{(eq. 9)}$$

$$Q_{C,LO,A,t} = MIN(Q_{C,Zone,t}, E_{C,A,I,t}) \quad \text{(eq. 10)}$$

3-2) Load offset by auxiliary equipment($Q_{LO,Aux,t}$)

The value gained by subtracting $Q_{LO,A,t}$ from $Q_{Zone,t}$. In this way, the heating load($Q_{H,LO,Aux,t}$) and cooling load($Q_{H,LO,Aux,t}$) offset by auxiliary equipment can be derived.

$$Q_{H,LO,Aux,t} = Q_{H,Zone,t} - Q_{H,LO,A,t} \quad \text{(eq. 11)}$$

$$Q_{C,LO,Aux,t} = Q_{C,Zone,t} - Q_{C,LO,A,t} \quad \text{(eq. 12)}$$

4) Calculate the remaining available and transformable energy after offsetting the load

4-1) Available energy($E_{A,AO,t}$)

This value can be derived by subtracting the load offset by available energy($Q_{LO,A,t}$) from the Initial available energy($E_{A,I,t}$). In this way, the remaining available for heating ($E_{H,A,AO,t}$) and the remaining available for cooling ($Q_{C,A,AO,t}$) after offsetting the cooling and heating load can be derived.

$$E_{H,A,AO,t} = E_{H,A,I,t} - Q_{H,LO,A,t} \qquad \text{(eq. 13)}$$

$$E_{C,A,AO,t} = E_{C,A,I,t} - Q_{C,LO,A,t} \qquad \text{(eq. 14)}$$

4-2) Transformable energy($Q_{T,AO,t}$)

As transformable energy is formed when offsetting loads, this value can be derived by summing the load offset by available energy($Q_{LO,A,t}$) and the initial transformable energy($E_{A,I,t}$). In this way, the remaining transformable energy in hot water tank($E_{H,T,AO,t}$) and the remaining transformable energy in chilled water tank($E_{C,T,AO,t}$) after offsetting the heating and cooling load can be derived.

$$E_{H,T,AO,t} = E_{H,T,I,t} + Q_{H,LO,A,t} \qquad \text{(eq. 15)}$$

$$E_{C,T,AO,t} = E_{C,T,I,t} + Q_{C,LO,A,t} \qquad \text{(eq. 16)}$$

5) Calculate the available energy gained by balancing($E_{A,Bal,t}$)

If the remaining transformable energy in hot water tank($E_{H,T,AO,t}$) smaller than the product of the remaining transformable energy in chilled water tank($E_{H,T,AO,t}$) and the balancing ratio(r_{HC}), the available energy for heating gained by balancing($E_{H,A,Bal,t}$) will be $E_{H,T,AO,t}$ and the available energy for cooling gained by balancing($E_{C,A,Bal,t}$) will be the value after dividing $E_{H,T,AO,t}$ by r_{HC}. If not, $E_{H,A,Bal,t}$ will be the product of $E_{C,T,AO,t}$ and r_{HC} and $E_{C,A,Bal,t}$ will be $E_{C,T,AO,t}$.

$$E_{H,U,Bal,t} = IF\left(E_{H,G,AO,t} < r_{HC}E_{C,G,AO,t}, E_{H,G,AO,t}, r_{HC}E_{C,G,AO,t}\right) \qquad \text{(eq. 17)}$$

$$E_{C,U,Bal,t} = IF\left(E_{H,G,AO,t} < r_{HC}E_{C,G,AO,t}, \frac{E_{H,G,AO,t}}{r_{HC}}, E_{C,G,AO,t}\right) \qquad \text{(eq. 18)}$$

6) Calculate the final available and transformable energy of current timestep

6-1) Available energy($E_{A,F,t}$)

This value is equal to the sum of the available energy after offsetting the load($E_{A,AO,t}$) and the available energy gained by balancing($E_{A,Bal,t}$). In this way, the final available energy for heating($E_{H,A,\mathrm{F},\mathrm{t}}$) and the final available energy for cooling($E_{C,A,F,t}$) can be derived.

$$E_{H,A,F,t} = E_{H,A,AO,t} + E_{H,A,Bal,t} \qquad \text{(eq. 19)}$$

$$E_{C,A,F,t} = E_{C,A,AO,t} + E_{C,A,Bal,t} \qquad \text{(eq. 20)}$$

6-2) Transformable energy($E_{T,F,t}$)

This value is equal to that gained by subtracting the available energy gained by balancing($E_{Bal,t}$) from the remaining transformable energy after offsetting the load($E_{T,AO,t}$) because the transformable energy is changed to the available energy by balancing. In this way, the final transformable energy in hot water tank($E_{H,T,\mathrm{F},\mathrm{t}}$) and the final transformable energy in chilled water tank($E_{C,T,\mathrm{F},\mathrm{t}}$) can be derived.

$E_{H,T,F,t} = E_{H,T,AO,t} - E_{H,A,Bal,t}$ (eq. 21)

$E_{C,T,F,t} = E_{C,T,AO,t} - E_{C,A,Bal,t}$ (eq. 22)

7) Calculate the factors for deriving the 'Percentage of the load offset by balancing'

7-1) Total zone load($Q_{Zone,tot}$)

This value is equal to sum of the zone load($Q_{Zone,t}$) (pro. 1) for heating and cooling in all timesteps.

$Q_{Zone,tot} = \sum Q_{H,Zone,t} + \sum Q_{C,Zone,t}$ (eq. 23)

7-2) Total zone load offset by balancing($Q_{LO,Bal,tot}$)

This value is equal to the sum of the load offset by balancing for heating and cooling at all timesteps. If the storage capacity of the tank is not too large, the all of available energy gained by balancing($E_{A,Bal,t}$) was used to offset the load. With this assumption, this value is equal to sum of $E_{A,Bal,t}$ (pro. 5) for heating and cooling in all timesteps.

$Q_{LO,Bal,tot} = \sum E_{H,A,Bal,t} + \sum E_{C,A,Bal,t}$ (eq. 24)

8) Derive the 'Percentage of zone load offset by balancing' (r_{Bal})

This value is equal to the value gained by dividing the total zone load offset by balancing($Q_{LO,Bal,tot}$) by the total zone load($Q_{Zone,tot}$) and then multiplying by 100 so that the result is expressed as a percentage.

$$r_{Bal} = \frac{Q_{LO,Bal,tot}}{Q_{Zone,tot}} \times 100 \qquad \text{(eq. 25)}$$

Fig. 2 Equaltions for process

4. Simulation

In this study, the percentage of zone load offset by balancing(r_{Bal}) was decided as the criteria when evaluating the Energy Balancing System. The zone load($Q_{Zone,t}$), the storage capacity of the tank(E_{Cap}) and the balancing ratio(r_{HC}) were then derived as the significant factors. In this simulation, the impacts of $Q_{Zone,t}$ will be evaluated by r_{Bal} of each season(heating, cooling, and intermittent), and the impacts of E_{Cap} and r_{HC} will be evaluated by r_{Bal} of one year.

4.1 Method

The input values of $Q_{Zone,t}$, E_{Cap} and r_{HC} are determined as shown below.

- To derive the zone load, a simulation was performed with a simple complex building model by EnergyPlus for one year with Incheon weather data applied [Tab. 2].
- The storage capacity of the tank is determined to be 20(GJ) for both tanks. This value was determined by multiplying by the maximum load with a safety factor of 1.3. The initial values of the initial available energy for heating and cooling are equal to the storage capacity. The initial values of the initial transformable energy for them are 0.
- The balancing ratio was determined to be 1.2 with the assumption that the cooling COP of the heat pump is 4.95.

Tab. 2: Input date for simulation

Contents		Floor area (m2)	Height (m)	Internal load (W/m2)		Fraction (-)			
						0~8 h	8~18 h	18~22 h	22~24 h
Building	Residential	2,500	3	People	26	1	0.2	0.8	0.8
				Light	12	0	0.5	1	1
				Equipment	5.4				
	Office	2,500	4	People	26	0	1	0	0
				Light	12				
				Equipment	10.8				
	Sports centre	3,600	4	People	262.5	0	1	1	0
				Light	15				
				Equipment	16.1				
	Commercial	4,900	5	People	65	0	1	1	0
				Light	18				
				Equipment	21.5				
Material		- Front/Back/Right/Left side : Curtain wall (Glass24mm, Argon, Glass32mm) - Ceiling/Floor : Slab (Gypsum12.5mm, Conc200mm, insulation20mm) - Between Interior Zone and Perimeter Zone : fiction wall							
Weather data		- Incheon, Republic of Korea							
Period		- 1 year: from 1st Jan. to 31st Dec. (Heating season: from 1st Dec. to 28th Feb Cooling season: from 1st Jun. to 31st Aug Intermittent season: from 1st Mar. to 31st May / from 1st Sep. to 30th Nov.)							

Ref.) Internal load: People (SAREK, 2001), Light/Equipment (ASHRAE, 2009)

4.2 Cases

To evaluate the impact of E_{Cap} and r_{HC}, comparing four cases [Tab. 3]: 1. Not considering E_{Cap} and r_{HC}; 2. Not considering E_{Cap} and considering r_{HC}; 3. Considering E_{Cap} and not considering r_{HC}; and 4. Considering E_{Cap} and r_{HC}. The impact of $Q_{Zone,\mathrm{t}}$ will be evaluated at each season for all cases.

Tab. 3: Cases for simulation

Case	Zone load $(Q_{Zone,t})$	Storage capacity of the tank (E_{Cap})	Balancing ratio (r_{HC})
1	O	X	X
2	O	X	O
3	O	O	X
4	O	O	O

5. Result & Discussion

The total zone load $(Q_{Zone,tot})$ should be equal to the sum of the total zone load offset by energy balancing$(\mathrm{Q_{LO,Bal,tot}})$, the total zone load offset by auxiliary equipment$(Q_{LO,Aux,tot})$, and the zone load offset by the initial available energy$(Q_{LO,A,I,ini})$. $Q_{LO,Bal,\mathrm{tot}}$ can be calculate by (eq. 24). $Q_{\mathrm{LO,Aux,tot}}$ is equal to sum of the load offset by auxiliary equipment (pro. 3-2) for heating and cooling in all timesteps. Regarding $Q_{LO,A,I,ini}$ as the amount of the initial available energy$(E_{A,I,ini})$ was not formed by balancing $Q_{LO,A,I,ini}$ should be accounted for separately. This value is equal to the value after subtracting the final available energy of the last timestep$(E_{A,F,last})$ from $E_{A,I,ini}$ because $E_{A,F,last}$ is not used to offset the load.

$$Q_{Zone,tot} = Q_{LO,Bal,tot} + Q_{LO,Aux,tot} + Q_{LO,A,I,ini} \qquad \text{(eq. 26)}$$

$$Q_{LO,Aux,tot} = \sum Q_{LO,Aux,t} \qquad \text{(eq. 27)}$$

$$E_{LO,ini} = (E_{H,A,I,ini} - E_{H,A,F,last}) + (E_{C,A,I,ini} - E_{C,A,F,last}) \qquad \text{(eq. 28)}$$

In this case study, the percentage of zone load offset by balancing(r_{Bal}) was evaluated as 16.6% to 23.6%. This result may small, but used energy for heating and cooling was reduced. The percentage of zone load offset by auxiliary equipment(r_{Aux}) was evaluated as 57.3% to 95.4%. The percentage of zone load offset by the initial energy$(r_{A,I,ini})$ was evaluated as 0% to 0.1% in cases considering E_{Cap} (cases 3 and 4).

To evaluate the impact of $Q_{Zone,t}$, the seasonal $\mathrm{r_{Bal}}$ of four cases should be compared. Comparing the seasonal $\mathrm{r_{Bal}}$ of between the cooling and intermittent season of cases 1 showed a difference of 20.7%; this difference was 21.3% when comparing cases 2; this difference was 36.4% when comparing cases 3; this difference was 38.1% when comparing cases 4. To evaluate the impact of E_{Cap}, one year $\mathrm{r_{Bal}}$ of cases 1 and 3 and cases 2 and 4 should be compared. Comparing cases 1 and 3 showed a difference of 6.0%; this difference was 6.4% when comparing cases 2 and 4. To evaluate the impact of $\mathrm{r_{HC}}$, cases 1 and 2 and cases 3 and 4 should be compared. When comparing cases 1 and 2, the difference was 0.6%, and the difference was 1.0% when comparing cases 3 and 4.

The impact of $Q_{Zone,t}$was most significant factor, therefore this factor should be considered when deciding to install the Energy Balancing System for buildings. Between another two factors, the impact of E_{Cap} is much higher than that of $\mathrm{r_{HC}}$. Moreover, the impact of E_{Cap} will be much higher as the storage capacity increases, while $\mathrm{r_{HC}}$ cannot vary much because the cooling COP cannot vary largely. However, E_{Cap} is closely related to the cost increase, therefore the optimal tank capacity should be estimated. The impact of $\mathrm{r_{HC}}$ was small. As the value of the factor increases, the impact of this factor also increases. However, the cooling COP is seldom under 3, so this value cannot be over 1.3. In this simulation, the cooling COP was 4.95, so the impact of this factor was small.

The result of this simulation is shown in [Fig. 2].

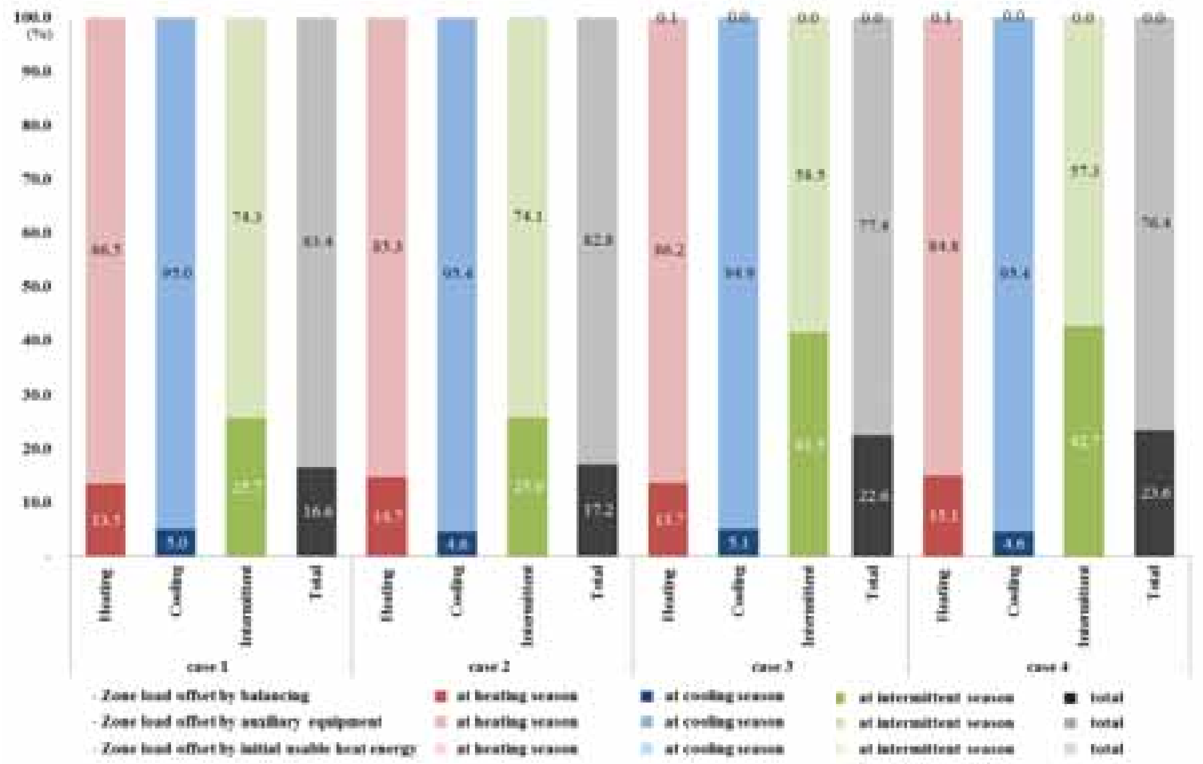

Fig. 3: Result of simulation

6. Conclusion

In this study, an evaluating method for the Energy Balancing System was developed and the significant factors which can affect at the energy balancing process are evaluated. The conclusions of this study are shown below.

- The evaluating method for the Energy Balancing System was developed. The percentage of zone load offset by balancing(r_{Bal}) is determined as criteria, and the zone load($Q_{zone,t}$), storage capacity(E_{Cap}) and the balancing ratio(r_{HC}) are determined as significant factors. Through the utilization of this method, the effectiveness of the Energy Balancing System can be evaluated for various super-large complex building components quantitatively.
- The impacts of three significant factors were evaluated by simulation. The impact of the zone load($Q_{zone,t}$) was most significant. Therefore it is necessary to consider this factor when deciding to install the Energy Balancing System for buildings. The impact of the storage capacity of tank(E_{Cap}) will be much higher as the storage capacity increases. However, it is necessary to estimate the optimal tank capacity considering the cost increase. The impact of the balancing ratio(r_{HC}) was small because the cooling COP was large enough. The impact of this factor will be larger in case of small cooling COP.
- In the case study, the total zone load offset by balancing($Q_{Bal,tot}$) was 23.6% with considering the storage capacity of the tank(E_{Cap}) and the balancing ratio(r_{HC}). From the viewpoint of energy, it will be positive situation because the input energy was reduced. However, this can be negative from the viewpoint of cost. Therefore, it is necessary to compare the consumption of energy and cost with conventional systems.
- This study was performed under the assumption of an ideal situation in which the zone load can be converted to available energy without a loss (in contrast to an actual), and storage capacity was evaluated with energy and not water (super-heating and super-cooling cannot be considered). It was assumed that the energy in storage can be monitored precisely and that the heat pump can operate under any condition. Therefore, it is necessary to consider a condition under which the system can operate in a future work.

Nomenclatures

Variables

$Q_{Zone,\mathrm{t}}$: The zone load (J)
$Q_{Zone,\mathrm{tot}}$: The total zone load (J)
$Q_{\mathrm{LO,A,t}}$: The load offset by the available energy (J)
$Q_{\mathrm{LO,Aux,t}}$: The load offset by auxiliary equipment (J)
$Q_{\mathrm{LO,Aux,tot}}$: The total load offset by auxiliary equipment (J)
$Q_{\mathrm{LO,Bal,tot}}$: The total zone load offset by energy balancing (J)
$Q_{LO,A,\mathrm{I,ini}}$: The load offset by initial available heat energy (J)
E_{A} : The available energy (J)
E_{T} : The transformable energy (J)
$E_{\mathrm{A,I,t}}$: The initial available energy of the current timestep (J)
$E_{T,\mathrm{I,t}}$: The initial transformable energy of the current timestep (J)
$E_{A,\mathrm{AO,t}}$: The remaining available energy after offsetting the load (J)
$E_{T,\mathrm{AO,t}}$: The remaining transformable energy after offsetting the load (J)
$E_{A,\mathrm{F,t}}$: The final available energy of the current timestep (J)
$E_{T,\mathrm{F,t}}$: The final transformable energy of the current timestep (J)
$E_{A,\mathrm{Bal,t}}$: The available energy gained by balancing (J)
$\mathrm{E}_{A,\mathrm{I,ini}}$: The initial available energy (J)
$\mathrm{E}_{A,\mathrm{F,last}}$: The final available energy of the last timestep (J)
E_{Cap} : The storage capacity of the tank (J)
r_{Bal} : The percentage of zone load offset by balancing (-)
r_{Aux} : The percentage of zone load offset by auxiliary equipment (-)
$r_{A,I,ini}$: The percentage of zone load offset by the initial energy (-)
r_{HC} : The balancing ratio (-)
COP_C : The cooling COP (-)

Subscripts

C : in chilled water tank
H : in hot water tank

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