STUDY ON LOAD PREDICTION WITH OPERATION DATA FOR CONTROL OF THERMALLY ACTIVATED BUILDING SYSTEM

Woong June Chung[1], Dae Uk Shin[1], Yoon Bok Seong[2], Myoung Souk Yeo[3], Kwang Woo Kim[3*]
[1]Department of Architecture and Architectural Eng., Graduate School of Seoul National University, Seoul Korea
[2]Korea Institute of Construction and Transportation Technology Evaluation and Planning, Korea
[3]Department of Architecture and Architectural Eng., College of Eng., Seoul National University, Seoul Korea

ABSTRACT

A type of a radiant system that uses the building concrete structure as energy storage, Thermally Activated Building System, is an energy efficient system, which utilizes the time-delay effect. Although the time-delay effect of the Thermally Activated Building System may be beneficial for the use of energy storage, it may also cause difficulties while controlling the system. When the system is not controlled properly, overheating and overcooling statement in the room and condensation on the surface may occur. For the proper use of the Thermally Activated Building System, the system has to provide the energy into the room as much as the amount of heating and cooling loads while keeping the setpoint temperature in the room. Since the starting operation time of the Thermally Activated Building System does not accord with the starting time of energy provided into the room, 1) heating and cooling load should be predicted and 2) the time delay of the thermal output of the Thermally Activated Building System needs to be analysed. This research is a preliminary study on the first part of the optimal operation of the Thermally Activated Building system, which presents a method to predict the heating and cooling loads with the operation data.

INTRODUCTION

The depletion of energy resource causes the increase of the energy cost, which raises the significant issues with energy consumption. Many researches on the energy conservation of buildings were performed, because the development of the building energy conservation was the slowest among industry, transportation, and building field. In order to conserve the energy in buildings, the use of the cooling and heating terminal system should be more efficient. First concept of method is to improve the efficiency of each component in plant, terminal, and distribution fields and second concept of method is to apply the proper energy-efficient system. Currently, air system removes the heating and cooling loads because of the advantages of instantaneous load removal, however the air system has great amount of energy consumption. Instead of the air system, one of the energy efficient terminal systems, Thermally Activated Building System, may be applied for escalating the efficiency of the system. The Thermally Activated Building System uses the time-delay effect to store the energy ahead of time in the concrete structure by supplying the water into the embedded pipes in the concrete structure.

Thermally Activated Building System saves more energy than the air system, because the pump of the Thermally Activated Building System consumes less amount of energy than the fan in the air system. The optimal operation of the Thermally Activated Building System is described in Figure 1, which shows the concept of the operating the Thermally Activated Building System ahead of time to remove the most of the building loads. However, the time-delay effect of the Thermally Activated Building System may cause difficulties for the control strategy. Thus, the auxiliary air system needs be integrated into the system to remove the remaining loads and systems are described in Figure 2.

In order to maximize the load handled by the Thermally Activated Building System and minimize the use of the air system, the Thermally Activated Building System needs to supply the water ahead of time according to the load occurrence and time-delay effect of the system. In this paper, the first part of the study on the optimal operation of the Thermally Activated Building System, load prediction, was performed for the maximum use of the Thermally Activated Building System was performed to conserve the energy.

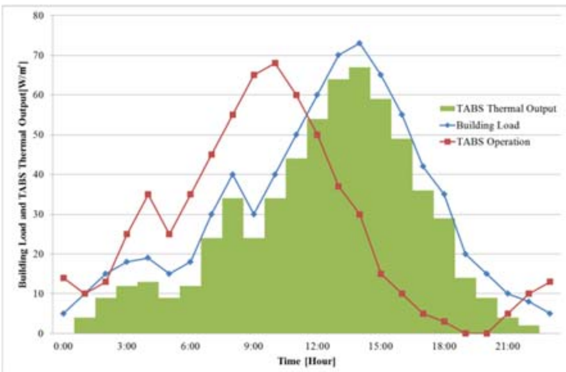

Figure 1 Concept of Ideal operation of the Thermally Activated Building System

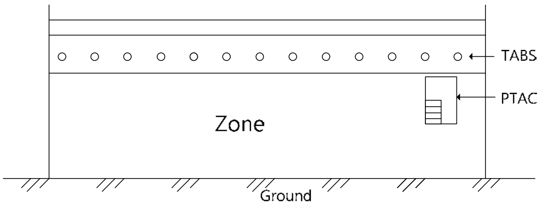

Figure 2 Schematics of the terminal system

APPLICATION

Difficulty of using the Thermally Activated Building System occurs on the control of the system because the temperature of concrete cannot be easily controlled due to the high heat capacity of the concrete structure. When the supply water temperature of the Thermally Activated Building System is too high during the winter, the overheating statement in the room may occur. In addition, when the supply water temperature is too low for the summer, the overcooling statement in the room and the condensation on the surface may occur. Therefore, the supply water temperature should be carefully determined to handle the heating and cooling load for preventing the problems.

The Thermally Activated Building needs the proper operation because of the time-delay effect from the high heat capacity of the concrete structure, which may be also the advantage of the system. The high heat capacity may decrease the peak heating and cooling loads of the buildings, however the loads cannot be removed instantaneously. Thus, the typical operation of the Thermally Activated Building System was performed by supplying the constant water temperature to remove the minimum amount of expected heating and cooling loads such as base load and the rest of the load was removed by the air system.

In previous researches on the control of the Thermally Activated Building System, the objective was to increase the amount of heating and cooling loads handled by the Thermally Activated Building System. Previous research on the control of the Thermally Activated Building System handled more heating and cooling loads by accounting the outdoor temperature, solar heat gain, and internal heat gain separately. As a control strategy, the outdoor reset control was used to compensate for the outdoor air temperature. When the outdoor reset control was applied, the outdoor temperature was measured and the solar heat gain and the internal heat gain were estimated with simulation. Depending on the building characteristics, the different heating curve and cooling curve for the outdoor reset control could be achieved.

The outdoor reset control for the Thermally Activated Building System was improved with consideration of uncertainty, which is called Unknown-But-Bounded method. The control strategy considered about the uncertainty of the solar heat gain and internal heat gain. The solar heat gain and the internal heat gain defined the lower bound and higher bound of the total heating and cooling loads, which classified the small, medium, and large heat gain range. As the difference of the lower bound and the higher bound becomes greater, the uncertainty of the heating and cooling loads increased. Thus, Unknown-But-Bounded method set the limit on the outdoor reset control to define the feasibility of the strategy. However, previous researches on the control of the Thermally Activated Building System had to expect a certain amount of the solar heat gain and the internal heat gain and were calculated in a steady state conditions. Moreover, the example in the previous research stated that the solar heat gain does not vary too much between the sunny and overcast conditions, which mean the amount of the solar heat gain is relatively small. If the great amount of the solar heat gain varies depending on the solar heat gain, the Unknown-But-Bounded may have high uncertainties to control the Thermally Activated Building System within the comfortable range. Therefore, the heating and cooling loads need to be predicted by approaching from the origin of the heating and cooling loads and handle with the understanding of the thermal output of the Thermally Activated Building System into the room. As preliminary studies to maximize the amount load handled by the Thermally Activated Building System, the load prediction in the winter season was performed.

METHODS

Load prediction can be separated into two steps for applying the method on the existing buildings. The first step of the load prediction needs to consider the characteristics of buildings through the operation data, because the performance of the existing buildings may differ from the actual design and the building and time-delay effect of the building and the system may change as the building decays. As a second step of the load prediction, the load prediction of the buildings can be performed with the building characteristics obtained from the first step of the load prediction. Overall concept of the method was demonstrated in Figure 4.

In order to find the building characteristics, the building loads are separated into ventilation load, external load, solar load and internal load and the unknown and known factors of building load defined. Then, the building operation data of the air system was observe to find the building characteristics. Since air system may remove the load without any time-delay effect, the operation data of the air system was used. The building characteristic measurements from the operation data were applied to predict each load.

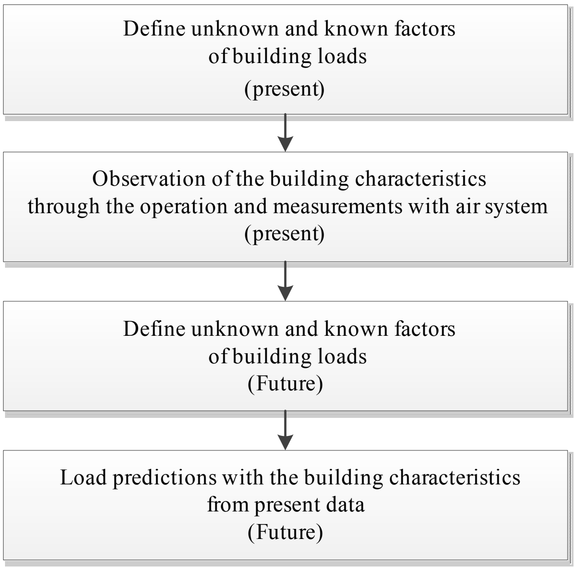

Figure 1 Flow diagram of building load prediction

Step 1. Observation of the building characteristics through the operation without the building data

In order to predict the building load, building characteristics should be observed by operating the air system and the building characteristics should be utilized to predict the building load.

1) Identification of unknown and known information of the building heating load calculation was performed as Table 1. The known factors are obtained from the operation of the air system and the unknown factors are building characteristics

Table 1 Observation of building load factors with operation data

Loads	**Known Factors**	**Unknown Factors**
Ventilation load $Q_{sensible} = 0.33\ V\ (T_{inside} - T_{outside})$ $Q_{latent} = 720\ V\ (h_{inside} - h_{outside})$	V(volume flow rate), ΔT, Δh(absolute humidity)	None
External load $Q_e = K \times A \times (T_{outdoor} - T_{indoor})$	Delta T	K(conductivity coefficient), A(area)
Solar load $Q_s = I \times A \times$ transmittance	I (solar radiation)	A, transmittance
Internal load Q_i = Intensity x FloorArea x Ratio	None	Intensity, Floor Area, Ratio(schedule)

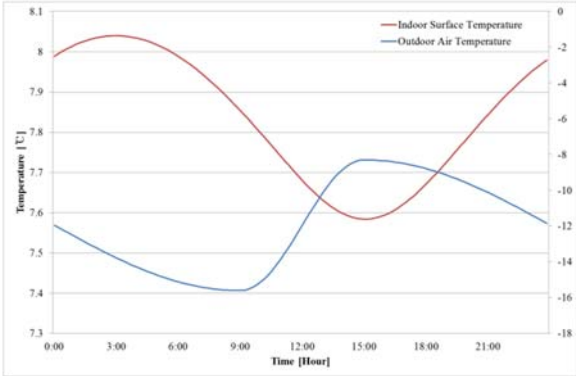

Figure 2 Time-delay effect of the external wall

2) With the identification of unknown and known factors of the building, the procedure of the achieving the building characteristics is described below.

a) Ventilation load

In order to calculate the ventilation load, the observation of the building load should be performed when there is no occupant at night. By measuring values of V, T_{inside}, $T_{outside}$, h_{inside}, and $h_{outside}$, sensible and latent ventilation load can be calculated.

b) External load

For calculating the external load, ventilation load should be subtracted from the total load when there is no occupant at night time period. The total load during the night without occupancy can be measured by observing the amount of heat supplied into the air system with the condition of keeping the setpoint temperature in the room. After calculating the external load, the $T_{outdoor}$ needs to be measured and then the value of K x A can be deducted.

Since the external load from the wall may cause the time-delay effect, the analysis of the load changes depending on the outdoor air temperature needs to be performed. Figure 5 explains how the internal surface temperature of the wall changes depending on the outdoor air temperature. For 200mm of the concrete wall, approximately 6hours of time-delay effect occurred.

c) Solar load

After obtaining the ventilation load and external load, the solar load can be achieved when the calculation is executed without any occupant during the day. Under the condition of keeping the setpoint temperature in the room with the air system operation, the heat supplied into the system was subtracted by the ventilation load and external load to calculate the solar load. With the solar load, unknown factors, A x transmittance can be ducted by measuring I.

d) Internal load

The internal load can be estimated by subtracting the ventilation load, the external load, and the solar load from the total load measured during the day. Depending on the occupant's behavior, the internal load will vary. Total load can be achieved by measuring the amount of heat supplied into the air system under the condition of keeping the setpoint temperature in the room.

The procedure of achieving the building characteristics can be set as the step 1. The unknown building characteristics, conductivity coefficient, wall area, window area, window transmittance, intensity of internal load, floor area, and ratio, are identified through the process. In step 2, the unknown factors are defined with building characteristics to predict the building loads.

Step 2. Load predictions with the building characteristics

1) Unknown and known information in each building load calculation with the building characteristics was identified as Table 2. Unknown factors in this step are weather conditions and known factors are building characteristics.

2) Since the unknown factors of building loads were weather data, the weather forecast information was utilized since the weather forecast is moderately accurate. The overall research concept of the load prediction is described in Figure 3.

Table 2 Observation of building load factors for load predictions

Loads	**Known Factors**	**Unknown Factors**
Ventilation load $Q_{sensible} = 0.33$ V (T_{inside}-$T_{outside}$) $Q_{latent} = 720$ V ($h_{inside} - h_{outside}$)	V, T_{inside}, h_{inside}	$T_{outside}$, $h_{outside}$
External load Q_e = K x A x ($T_{outdoor} - T_{indoor}$)	K x A, T_{indoor}	$T_{outdoor}$
Solar load Q_s = I x A x transmittance	A x transmittance	I
Internal load Q_i = Intensity x FloorArea x Ratio	Intensity, Floor Area, Ratio	None

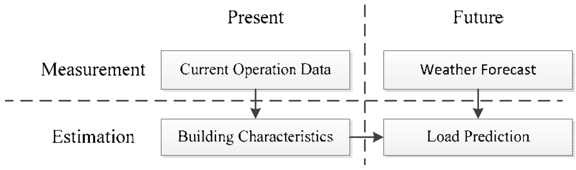

Figure 3 Research concept

a) Ventilation load ($Q_{sensible} = 0.33$ V (T_{inside}-$T_{outside}$), $Q_{latent} = 720$ V ($h_{inside} - h_{outside}$))

Outdoor temperature from the weather forecast was used to predict the sensible ventilation load.

Relative humidity in the weather forecast needs to be converted into an absolute humidty and substitued into the equation to predict the latent ventilation load.

b) External load (Q_e = K x A x ($T_{outdoor} - T_{indoor}$))

Same outdoor temperature from the weather forecast was used to calculate the external load. The time-delay effect observation from previous step needs to be applied when the Thermally Activated Building System is operated.

c) Solar load (Q_s = I x A x transmittance)

With the weather forecast of the cloudness, the solar radiation can be deducted and Q_s can be predicted.

d) Internal load (Q_i = Intensity x FloorArea x Ratio)

All of the factors in the internal load are defined as known in this study. Intensity of the internal load, floor area, and ratio changes depending on occupants behaviors. The typical occupant schedule was assumed in this study and relationship between occupant's behavior and the internal load will be statistically analyzed in the future study.

The weather forecast consists of the outdoor air temperature, the relative humidity, and the weather according to the cloud amount, which can be used in the load prediction. The weather forecast in Korea is relatively accurate and cqwan be directly substituted into the load equations.

Table 3 described the cloud amount according to the weather forecast. Direct, diffused, and ground reflected solar radiation passing through the window depends on the amount of cloud and the most

Table 3 Cloud amount according to the weather forecast

	SUNNY	**PARTLY CLOUDY**	**MOSTLY CLOUDY**	**CLOUDY**
Cloud amount	0~2	3~5	6~8	9~10

$$I_{GC} = 910 \sin\alpha - 30 \quad (6)$$

$$I_G = I_{GC}(1-0.75(N/8)^{3.4}) \quad (6)$$

Where, I_{GC} = Vertical quantity of solar radiation

α = Solar Altitude

I_G = Vertical quantity of solar radiation on a clear day

N = Cloud Amount

affected factor, direct solar radiation, should be analysed to estimate the total solar load. The cloud amount from weather forecast can be used to predict the amount of solar radiation. Kasten and Czeplak proposed the following formulas, which estimates the solar radiation based on the cloud amount information.

SIMULATION APPROACH

The ultimate goal is to build the control strategy of the Thermally Activated Building System and apply the strategy on the actual model. However, the feasibility of the control should be tested first in the simulation. Hence, the load prediction, the preliminary study on the optimized control strategy for the Thermally Activated Building System, was performed with the TRNSYS simulation to verify the accuracy.

For the research purposes, the simulation was performed on the typical residential building in Korea. The section view of the Thermally Activated Building System is demonstrated in Figure 6. The structure of the Thermally Activated Building System was designed into the concrete structure of the residential building. Since the typical residential building in Korea uses the screed to provide the heating from the floor, the Thermally Activated Building System was placed on the ceiling. In addition, the insulation was applied above the Thermally Activated Building System to prevent the heating upstairs and only provide heating downstairs, because the heating and cooling cost between upstairs and downstairs needs to be separated in residential buildings.

As a preliminary study, the simulation for the

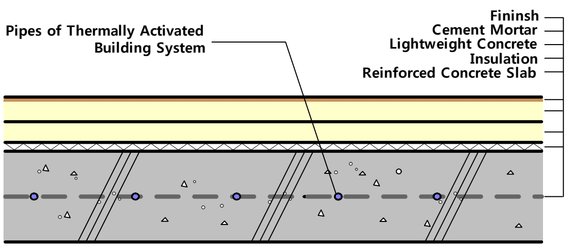

Figure 4 Section view of the Thermally Activated Building System

Table 4 Boundary conditions for the simulation

CONDITIONS	CONTENTS
Building Orientation	Southeast
District	Seoul, Korea
Area	29 ㎡ (6.6m x 4.4m)
Window	South 75%
Internal Heat Gain	2 people, 100W lighting, 150W equipment
Setpoint Temperature	20℃
Mass Flow Rate of Thermally Activated Building System	2 LPM
PTAC Operation	24 Hours of operation
TABS Placement	Ceiling (Slab)

Table 5 Cases of simulation

CASES	SYSTEM
Case 1	Air system only
Case 2	Air system integrated with Thermally Activated Building System (with the load prediction)

summer may cause difficulties of controlling due to the condensation on the surface. Thus, the simulation was performed on winter with 20 degrees of setpoint temperature. As the typical residential buildings in Korea, the façade has a large area of glazing, which will let the solar heat gain to enter the building. The cases of simulation was configured as Table 5 to compare the existing system and proposed system.

The case 1 uses only the air system to represent the conventional system of the buildings. And case 2 used the proposed method to handle the heating load to increase the amount of load handled by the Thermally Activated Building System and utilize the air system as an auxiliary system. Case 2 will follow the process of the load prediction that was shown in previous method section.

The simulation was performed on the main room as demonstrated in Figure 3, because it is the most used space in the residential building and the heating is

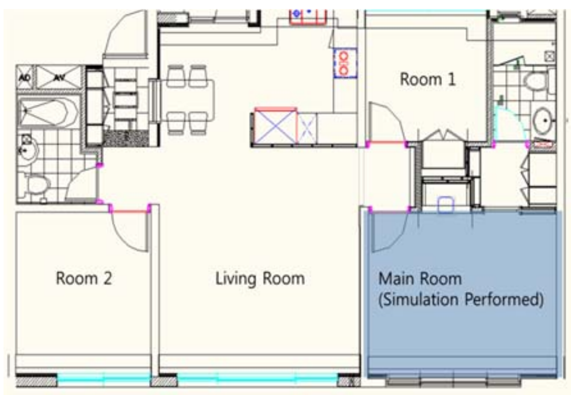

Figure 5 Plan view of the simulated space

required at night for occupants. The south façade of the main room had 75% of the glazing area, because the most of residential buildings expand the balcony and use more space for living. However, the expansion of the balcony removes a buffer zone that prevents heat loss and gain. Thus, the residential buildings have a poor envelop performance.

RESULTS AND DISCUSSIONS

With the calculation of the building load from the previous method section, the residential building was simulated with TRNSYS. In the process of calculating the ventilation load and external load, the weather forecast of the outdoor air temperature and the relative humidity were relatively accurate. The outdoor air temperature did not exceed the error of 1℃. Since the relative humidity did not dramatically change, the error was minor.

The solar radiation significantly varied compared to other types of loads. The diffuse solar heat gain and ground reflected solar heat gain remained relatively constant with the variance of the cloud. However, the direct solar heat gain had significant difference depending on the amount of the cloud. Thus, the

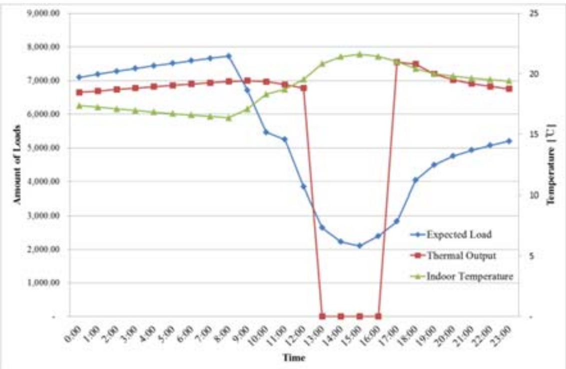

Figure 8 Thermally Activated Building System operation with load prediction in a peak day (January 16th)

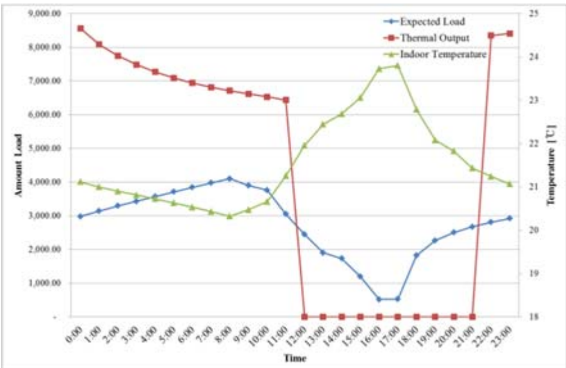

Figure 9 Thermally Activated Building System operation with load prediction in a day with constant heating load (January 21st)

weather forecast should be applied on the direct solar heat gain more than the diffuse solar heat gain and the ground reflected heat gain.

With the amount of load predicted from proposed method, the same amount of the energy was provided to the Thermally Activated Building System 6 hours ahead of time to deliver the heat into the room when the load occurs. Relatively good amount of the load was removed by the Thermally Activated Building Syste on a peak day as Figure 8. However, the problem occurred with simulation program even though the Thermally Activated Building System received the feedback from predicted load to remove the load.

As Figure 9 illustrated, the Thermally Activated Building System stop operating when the expected load become very small. One of the issues occurred when the Thermally Activated Building System operation discontinued. The indoor air temperature increased significantly more although there was no water supplied into the system. Even with the small amount of the solar heat gain, the indoor air temperature increased significantly, and it caused unnecessary energy consumption. The simulation results not only emphasized on the importance of the time difference between the energy input time into the system and energy output into the room, but also stressed on the period of time that the concrete structure holds the energy.

Another issue occurred in the simulation program to operate the Thermally Activated Building System. The simulation program has the "active layer" and it was applied to describe the Thermally Activated Building System. However, the Thermally Activated Building System does not operated when a small amount of load occurred, because of the minimum mass flow rate of the system. Minimum mass flow rate did not allow the pump to operation for improving the efficiency of the Thermally Activated Building System. Hense, the system did not operate according to the heating load prediction.

The sum of the heat provided into the room on a peak day is demonstrated in Table 4. The reason why the air system integrated with the Thermally Activated Building System has greater value of thermal heat into the room than the air system is that the unexpected heat was provided into the room. The time-delay effect of the Thermally Activated Building System changes depending on the supply water temperature, the mass flow rate, and the operation period, which are not yet analysed.

Table 4 Thermal heat provided into the room on a peak day (January 16th)

CASES	THERMAL HEAT INTO THE ROOM
Case 1	128,803
Case 2	138,733

After the analysis of the thermal output of the Thermally Activated Building System, the amount of the thermal heat into the room and the amount of predicted heating load would be similar. Since the pump of the Thermally Activated Building System consumes less amount of energy than the air system, the overall energy consumption for heating with the Thermally Activated Building System will be reduced.

CONCLUSIONS

The main objective of the study is to maximize the utilization of the Thermally Activated Building System. In order to achieve the goal, preliminary studies were performed as follows.

A preliminary study to improve the performance of the Thermally Activated Building System was achieved by developing the simple procedure of load predictions, which may be applied in existing buildings.

The building characteristics were observed through the operation data and were utilized for the load prediction, due to the decay of the building. In the process of the load prediction, the unknown factors were obtained from the weather forecast data, because the weather forecast data is relatively accurate.

Among the building load, the external load needs to consider the time-delay effect due to the capacity of the wall. The interior surface temperature of the wall and the outdoor temperature was compared to consider the time-delay effect.

As a future study, the time delay effect of the Thermally Activated Building System should be carefully analysed to provide the exact amount of thermal heat into the room according to the load prediction.

ACKNOWLEDGEMENT

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