FEASIBILITY OF A THERMALLY ACTIVATED BUILDING SYSTEM IN RESIDENTIAL BUILDINGS

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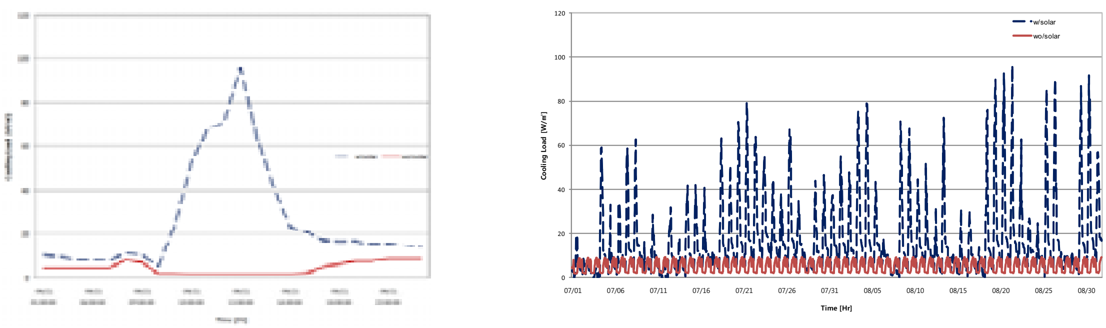
1. Introduction

A thermally activated building system is a radiant system that uses a concrete structure as a storage system. Unlike a regular storage system, a thermally activated building system uses the concrete structure as a storage system and it does not require any space. Utilization of the thermally activated building system increased in office buildings because it uses a mechanism of a radiant heat transfer that saves a building energy and provides better thermal comfort compared to an air system. Because the structures have a high heat capacity, the thermally activated building system was used to remove a large amount of constant internal loads and reduce the peak load with time-lag effect in office buildings.

Typical residential buildings experience irregular energy consumption due to differences in the behaviors by residents. Therefore the applicability of thermally activated building system in residential buildings should be approved by analyzing the loads of typical residential buildings and investigating the performance of the thermally activated building system. Fig.1 demonstrates the cooling load with and without solar radiation. Most of the load was the solar load and the thermally activated building system focused on removing the solar load.

For The packaged terminal air conditioner is commonly used to handle the cooling loads in residential buildings. As the residents of residential buildings demand better quality of their room conditions, the packaged terminal air conditioner consumes in increasingly large amount of energy and increases the peak load. For proper verification of the performance of the thermally activated building system, a packaged terminal air conditioner was integrated with the thermally activated building system. The packaged terminal air conditioner was used as a primary cooling system and the thermally activated building system was operated as a secondary system. Because the thermally activated building system could be operated by providing the high supply water temperature for cooling, the geothermal energy may be used.

In order to apply thermally activated building system in residential buildings, parameters of thermally activated building system should be analyzed. The main factors of the thermally activated building system are the design and control parameters. The design and control parameters are the layer configuration, the operation period, the starting time of operation, and the supply water temperature. Among the parameters of thermally activated building system, the most influential factor is supply water temperature. Supply water temperature was adjusted to achieve the proper temperature without any condensation and under-cooling problems.



(a) Peak Day **(b) Two Months**

Fig.1: Comparison of Cooling Load with and without Solar Radiation

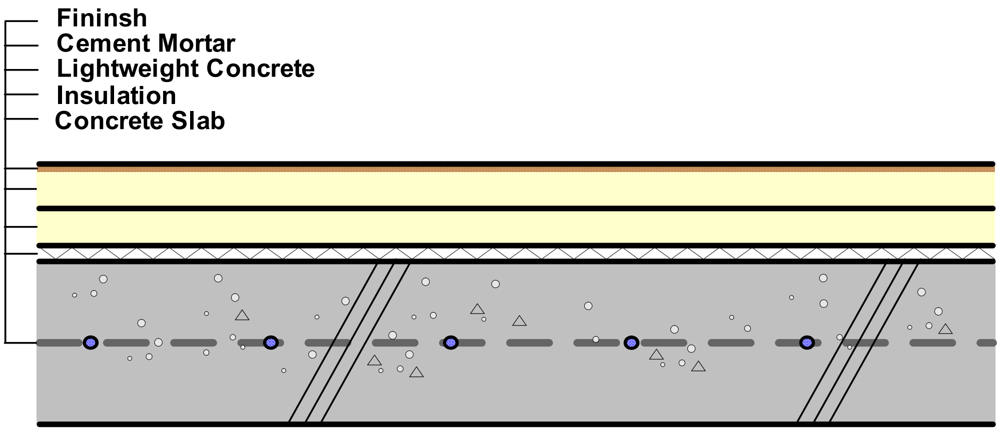


Fig.2: Layer Configuration of Thermally Activated Building System

Method

The thermally activated building system stores the coolness ahead of time in the structures of the building and releases it when residential building consumes a high level of energy. However, condensation on the surface of the structure and an under-cooled state of the building can be problems related to utilization in a thermally activated building system. Condensation on the surface of the structure may lead to the formation of mold on the surface, which can damage the finish. An under-cooled state of the building will make the occupants feel discomfort and consume unnecessary energy.

In order to properly verify the performance of the thermally activated building system, typical cooling system of residential building, the packaged terminal air conditioner, was integrated with thermally activated building system. Packaged terminal air conditioner was used as a primary cooling system and the system was simulated with EnergyPlus.

A thermally activated building system has design and control parameters. One design parameter is the layer configuration of the system. Control parameters are the operation period and the operation starting time. The mutual element in both the design and the control parameters is the supply water temperature of the thermally activated building system. Fixed elements were layer configuration, operation period, and starting time of operation and variable element was supply water temperature. This paper proposes that the supply water temperature determines the maximum load ratio, which is the ratio of the peak load to amount of load handled by the thermally activated building system.

2.1 Design Parameters of Thermally Activated Building System

The layer configuration of the thermally activated building system includes the concrete, finishes, piping, and the depth of the piping, as investigated in previous research. Based on the significance of the elements that was approved by the previous research, the layers configuration of the thermally activated building system was developed. The structure of the thermally activated building system is in the order of finish (9mm), cement mortar (45mm), lightweight concrete (45mm), insulation (20mm) and concrete slab (200mm). The pipes of the thermally activated building system are located in center of concrete slab. Fig.2 demonstrates the layer configuration of the thermally activated building system.

2.2 Control Parameters of Thermally Activated Building System

The operation period and operation starting time are two control parameters of the thermally activated building system. Because the heating load and cooling load of an office building occur mostly during the day, office buildings in Europe use a thermally activated building system to store heat at night for 12 hours. Considering the schedule of residential buildings, the thermally activated building system was operated during the day for 12 hours to handle the large amount of the solar load. The boundary conditions for the EnergyPlus simulation are given in Tab.1.

After determining the boundary conditions for the design and control parameters, the mutual element in the design and control parameters, the supply temperature, should be determined considering the load profile, condensation and under-cooled period.

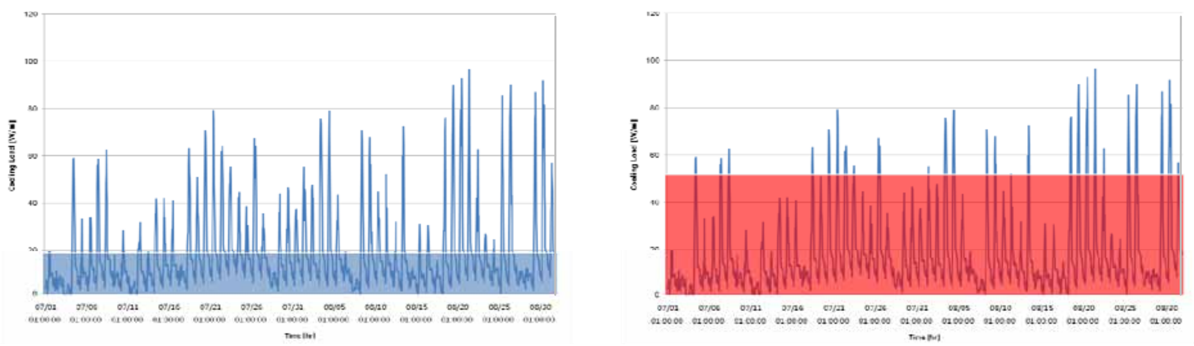
Tab.1: Boundary Conditions of Typical Residential Buildings

Conditions	Content
Building Orientation	Southeast
District	Seoul, Korea (weather data used)
Area	29m^2 (6.6m x 4.4m)
Window	South 75% (typical residential building)
Internal Heat Gain	2 people, 100W lighting, 150W equipment
Setpoint Temperature	Typical summer setpoint temperature 26℃
Blind	0.2 Reflectivity
Thermally Activated Building System Operation Period	12 Hours of operation
Thermally Activated Building System Starting Time of Operation	10:00~22:00
Packaged Terminal Air Conditioner	24 Hours of operation
Thermally Activated Building System Placement	Ceiling
Ventilation System	Heat Exchanger

2.3 Mutual Element of Design and Control Parameters of Thermally Activated Building System

The amount of heat output of the thermally activated building system should be considered to determine the supply water temperature. The heat output of the system was calculated with EN1264 and determined according to the maximum load ratio. The maximum load ratio of a thermally activated building system can be controlled by the supply water temperature. When the supply water temperature is low, the thermally activated building system handles a large amount of cooling load and the maximum load ratio is high. However, the risk of condensation and under-cooling increases and the operation time should be controlled. When the supply water temperature is high, the thermally activated building system handles a low cooling load and the maximum load ratio is low. However, the thermally activated building system can be operated with constant supply water without any control strategy. Fig.3 explains how the load could be handled by the thermally activated building system.

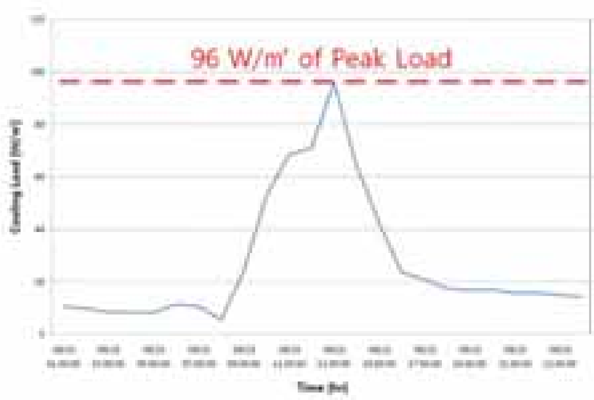
In this study, a simulation was performed to determine the appropriate maximum load ratio and the lowest supply water temperature of the thermally activated building system. The supply water temperature of the thermally activated building system was determined by analyzing the load profile, condensation on the surface, and under-cooled condition of a residential building.



(a) Low Load Handled – Simple Control

(b) High Load Handled – Complex Control

Fig.3: Cooling Load Handled by Thermally Activated Building System



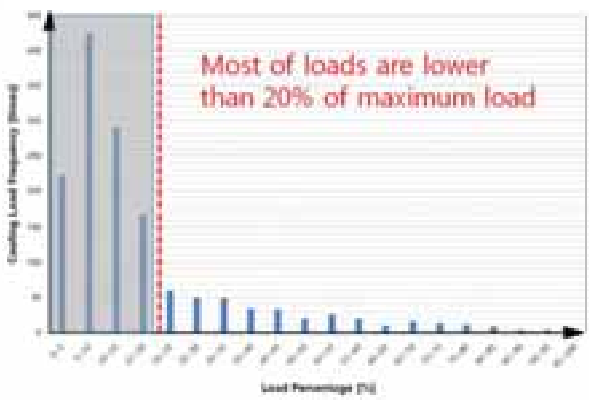


Fig.4: Cooling Load on Peak Day

Fig.5: Load Frequency of the Residential Building

2.3.1 Load Profile

A typical residential building was simulated by EnergyPlus to analyze the cooling load profile. The simulation was performed in July and August. Fig.4 demonstrates the cooling load on the peak day. Most of the load patterns were similar to the graph, and the peak load of 96 W/㎡ occurred on August 21^{st}.

The cooling load occurs during the day, as residential buildings have large windows and because the largest cooling load was caused by sunlight entering the room from 8am to 6pm. With the peak load, the cooling load frequency is described in Fig.5.

The load percentage is the cooling load divided by the peak load. The bar graph of the load profile shows that most of the cooling loads are lower than 20% of the maximum cooling load. The thermally activated building system should handle most of the cooling load.

2.3.2 Supply Water Temperature Considering Condensation and Under-cooling Period

With the EnergyPlus simulation, each case was simulated with a different supply water temperature. The supply water temperature was calculated with the EN1264 standard and the maximum load ratio. The maximum load ratio was applied in increments of 10. When the maximum load ratio was 70% almost the entire cooling load was handled by the thermally activated building system.

Depending on the maximum load ratio and supply water temperature of the thermally activated building system, the heat output of the thermally activated building system, volume flow rate, packaged terminal air conditioner energy consumption, percentage of time in which condensation occurred, percentage of time in which under-cooling occurred, and the handled load percentage. The heat output, supply water temperature and volume flow rate were calculated with EN1264 before the simulation. The heat output of the thermally activated building system changed according to the maximum load ratio. After the heat output was determined, the supply water temperature was calculated for each heat output value. The volume flow rate changed according to the supply water temperature.

2. Results and Discussions

3.1 Result analysis and consideration for application of thermally activated building system

The application of the thermally activated building system should be determined during the design process because the system should be incorporated into the structure of the building. The correct capacity of the system can provide the proper supply water temperature and the maximum load ratio.

This study provides a method to apply the thermally activated building system appropriately. If the thermally activated building system is applied in a different country with lower humidity, the supply water temperature can be lower and the system may be more effective. In this case, the weather was simulated in Seoul, where the humidity is higher than many other cities and countries.

In the simulation, typical residential building model used 702 kWh with the packaged terminal air conditioner. However, the packaged terminal air conditioner integrated with the thermally activated building system used 454 kWh.

Tab.2: Comparison of Factors of Different Maximum Load Ratio

Maximum Load Ratio [%]	Heat Output [W/㎡]	Supply Water Temperature [℃]	Volume Flow rate [LPM]	PTAC Energy Consumption [kWh]	Condensation Ratio [%]	Under-cooling Ratio [%]	Load Handled Percentage [%]
0	-	-	-	703	-	-	-
10	10	23	1.3	586	-	-	22
20	19	20	2.7	455	-	-	44
30	29	17	4.0	339	1	10	62
40	39	14	5.3	240	5	32	76
50	48	12	6.7	163	16	61	85
60	58	9	8.0	102	30	77	91
70	67	7	9.3	56	44	6	96

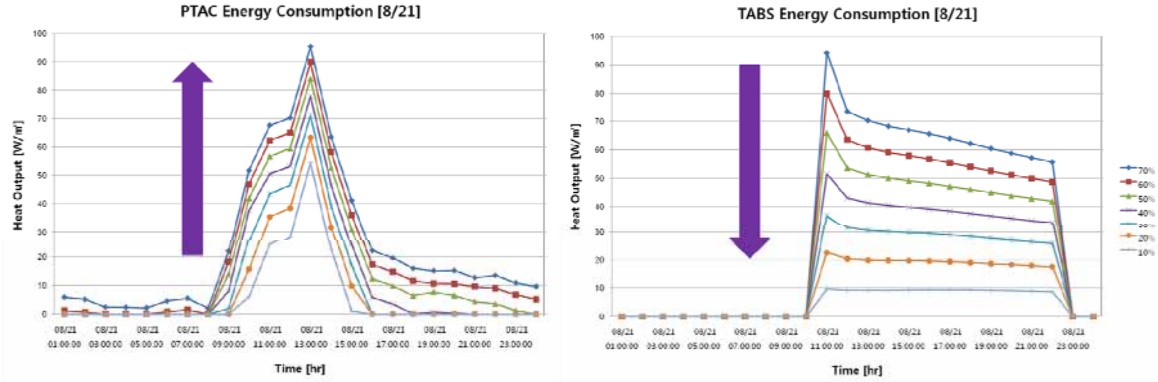
3.2 Reduction of Peak Load by Thermally Activated Building System

The result provides a comparison of the energy consumption of the two cooling systems. The first cooling system was the packaged terminal air conditioner and the second cooling system was the packaged terminal air conditioner integrated with the thermally activated building system.

The thermally activated building system is feasible to used geothermal energy with a heat exchanger, because the thermally activated building system is operated with the high supply water temperature for cooling. In simulation, the geothermal energy was applied and the result of simulation is demonstrated in Tab.2.

Because condensation and under-cooling are a critical factor in a radiant system, the appropriate maximum load ratio was 20% with a heat output of 19 W/㎡ and a supply water temperature of 20℃. The energy consumption of the packaged terminal air conditioner was reduced by 35% and the time the packaged terminal air conditioner was used was decreased by 27%. The thermally activated building system handled 44% of the total cooling load for July and August.

Fig.6 describes the patterns of the load handled by the packaged terminal air conditioner and the thermally activated building system for different maximum load ratios on the peak load day. As the maximum load ratio increases, packaged terminal air conditioner uses less energy and the thermally activated building system uses more energy.



(a) Packaged Terminal Air Conditioner **(b) Thermally Activated Building System**

Fig.6: Cooling Load Handled for Different Maximum Load Ratio

3. Conclusion

The study provides the result of a performance check of a thermally activated building system and a correct method to apply a thermally activated building system to a typical residential building. The load profile, condensation and under-cooling of the residential building was analyzed and selected the correct maximum load ratio. The findings are summarized below.

1. Significant factors of the thermally activated building system were the design parameters and the control parameters. The elements of the design and control parameters are the layer configuration, the operation period, the starting time of operation and the supply water temperature.
2. As the supply water temperature becomes lower, the maximum load ratio and the load handled percentage of the thermally activated building system increased. Previous researches proposed 15℃ and 17.5℃ without considering the under-cooling. However, this study concluded that 20℃ of the supply water temperature was the most appropriate temperature.
3. The method to apply the thermally activated building system in residential building is proposed by analyzing the load profile and considering the condensation and the under-cooling. The thermally activated building system was applicable to residential building because the system handled most of the solar load. The system reduced 10% of the peak load and 35% of the total cooling load with geothermal energy.These results introduce a feasible method with which to design and operate a thermally activated building system. In a future study, a thermally activated building system may apply different solutions for the control parameters to increase the load handling percentage.

4. Acknowledgement

This study was supported by Energy • Resources Technology R&D program (2008-E-BD11-P-13-0) under the Ministry of Knowledge Economy, Republic of Korea. The authors thank these institutions for their support. This would be beneficial for lower cooling energy consumption with similar levels of room temperature.

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