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A demonstration study of cooling system assisted with thermal energy storage system using phase change material

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Abstract

At the 21st COP (Conference of Parties), the agreement was made by representatives of 195 countries. It requires all participated countries have to active against the climate change. Before reached this agreement, Korea government had announced a plan to reduce the country's greenhouse gas emission by 37 percent from the BAU (business-as-usual) level of 2030 year. Under this trend, the energy network technology has attracted to one of key research activities to meet above goals. KIER (Korea institute of energy research) headquarter is a suitable site for demonstrated research of the energy network technology because it has various heat facilities such as geothermal heat pump, solar collector, fuel cell and coal-fired power plant. For a demonstrated research, the lab-scale TESS (thermal energy storage system) was constructed in KIER. Its purpose is to reduce energy consumption by relieving time differences between thermal energy generation and consumption. To achieve its goal, TESS was constructed with an air to air heat pump and PCM (phase change material). Also an KIER EMS (energy management system) had accumulate measured data to provide information to decision-maker to optimal operate the system. As results of a preparatory experiment, TESS could shift the cooling loads and it might improve the primary energy efficiency by 33% compared to conventional absorption chiller system.

Keywords: TESS, Heatpump, PCM, EMS

1. Introduction

Peak demand control is one of major issues related to national energy policies. Fig. 1 shows the trend of peak demands and supply capacity reserve margin of Korea. The demands have continuously increased. This caused the reserve margin below 5% in 2012. In such a low margin, the possibility of black out would increase dramatically. Thermal energy storage system (TESS) generates and stores heat during low load period. The stored energy is generally used in high load period. Therefore it has a high potential in decreasing peak load demand. Common types of TESS are ice storage system and chilled water storage system. Due to the latent heat of ice, ice storage system has high thermal energy storage density. However it requires low working fluid temperature and this makes the performance of chiller poorer. In contrary to ice thermal system, chilled water system uses the sensible heat of water. It can be used for both heating and cooling. However it requires larger storage volume and installation space. In this study, phase change material which has melting temperature suitable for cooling is

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applied to increase thermal storage density and efficiency of chiller. A pilot system was designed and built for two offices of KIER (Korea Institute of Energy Research). Demonstration operation was conducted during the summer season of 2016. The results showed that more than 30% energy increase was expected compared to current central cooling system of KIER.

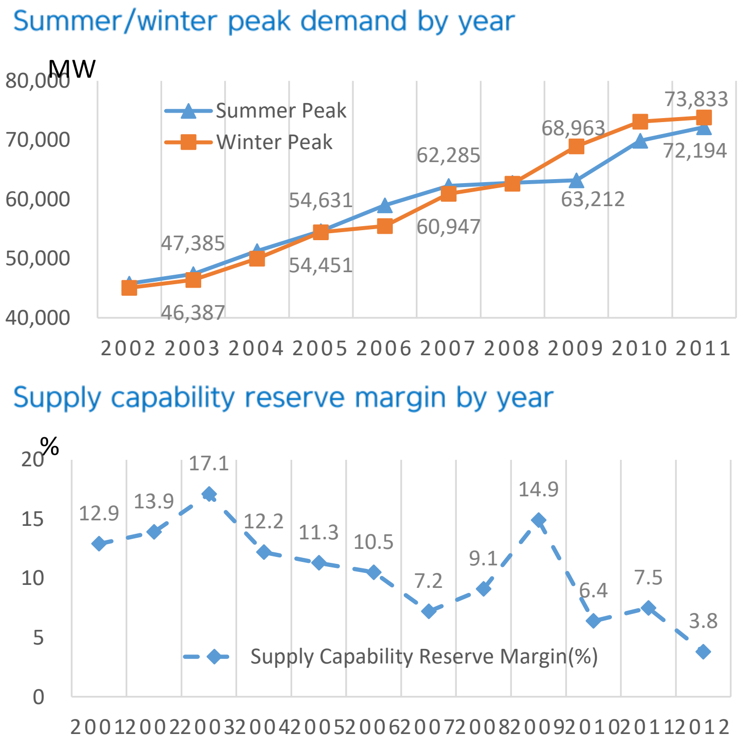

Figure 1. Trend of peak loads and reserve margin of Korea

2. Design of thermal energy storage system

Absorption chiller heater is the main cooling facility of KIER and table 1 is the specification of it. The COP based on primary energy usage is 1.04. This value corresponds to COP of 2.6 based on electricity energy when the power generation efficiency is assumed as 0.4.

Table 1. Specifications of absorption chillers for central cooling and heating of KIER

Capacity			Supply temperature	Energy consumption		
				LNG (Nm^3/hr)	LPG (Nm^3/hr)	Electricity (kW)
Cooling	320	USRT	12/7℃	87.4	-	4
Heating	967,680	kcal/h	55/60℃	102.5	-	
Cooling	600	RT	12/7℃	163.5	-	13
Heating	1,814,400	kcal/h	55/60℃	202.7	-	

Two offices were selected as the test site for the demonstration operation of TESS. Energy saving and load shaving effect were evaluated for these offices. TRNSYS simulation was performed to estimate cooling and heating demands characteristics of the target offices. Fig. 2 represents simplified office models and thermal characteristics for the evaluation. Table 2 is the simulation results of maximum cooling load for target offices for summer season. Based on these results, the capacity of TESS was determined as 76000 kJ with maximum output of 2.1 kW.

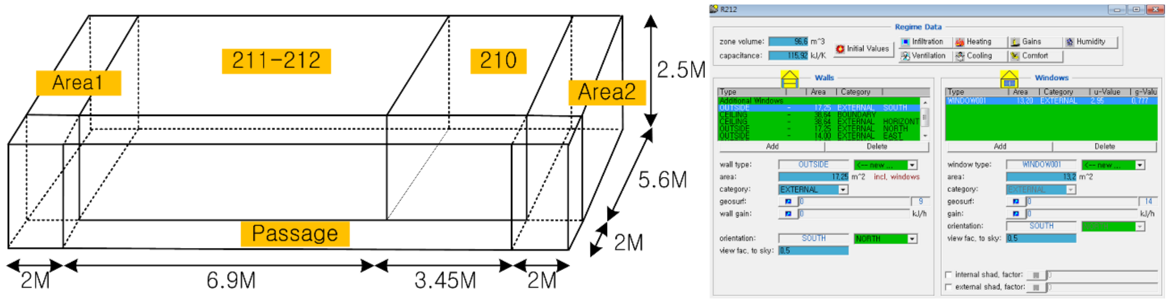

Figure 2. Simplified building model and boundary conditions

Table 2. Simulation results of maximum cooling load of target offices

	Room A		Room B	
	Load per area	Total load	Load per area	Total load
Daily accumulated	896 Kcal/㎡	72,000 kJ	830.9 Kcal/㎡	130,000 kJ
Peak load	0.12 kW/m2	2.2 kW	0.11 kW/m2	4.4 kW

For thermal energy storage, ice storage, chilled water storage and phase change material (PCM) storage methods can be applied. Ice storage type is the most compact method but it requires low evaporation temperature of chiller. Chilled water type needs larger installation space. Therefore, PCM storage method was used in this study. The selected PCM has melting temperature of 3~5°C and Table 3 shows properties of it.

Table 3. Properties of phase change material for cooling heat storage

	Melting temperature (°C)	Latent heat (kJ/kg)	Density (kg/l)	Specific heat (kJ/kg/K)
PCM	3~5	252.30	0.825	2.07

The volume of storage tank was 1 m^3. The charge amount of PCM was determined as the ratio of latent heat to sensible heat should be 3.

3. Construction of a pilot system

Heat source for TESS was supplied by heat pump system. Considering the thermal load of target offices, the capacity of heat pump was selected as 2 RT. BLDC compressor was applied to increase efficiency of partial load operation since it reduces inefficient on/off operations. Fig. 3 is the schematic diagram and installation pictures of TESS.

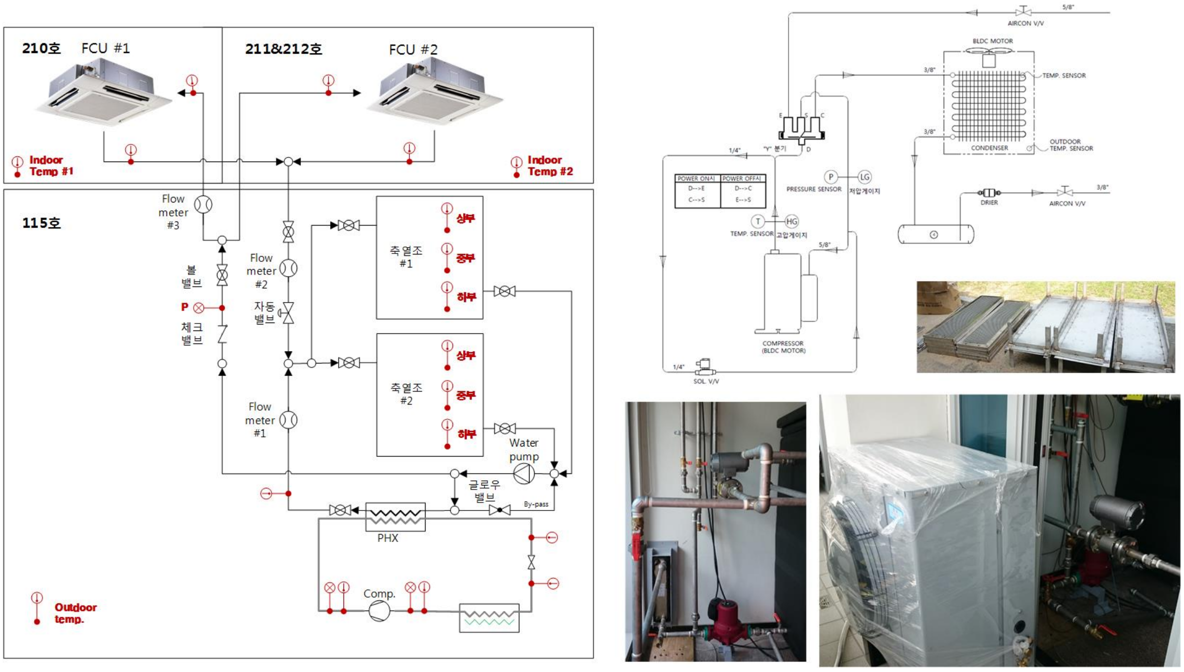

Figure 3. Schematic diagram of TESS and pictures of its components

The TESS was designed to perform various operation mode such as storing, releasing, releasing with heat pump and heat pump only. The modes should be selected both through web-server and local control panel. Considering the wide spreads of pilot system, design of control and communication layout was performed. All the hardware can be controlled through web-server. Controlling all the hardware by web will require tremendous load if pilot systems are applied to the entire buildings. Then the maintenance will be difficult. Therefore the layout was designed so that each local panel take the role of optimum control and web server send signal for pre-defined operation modes. Fig. 4 shows the design concept of this communication layout.

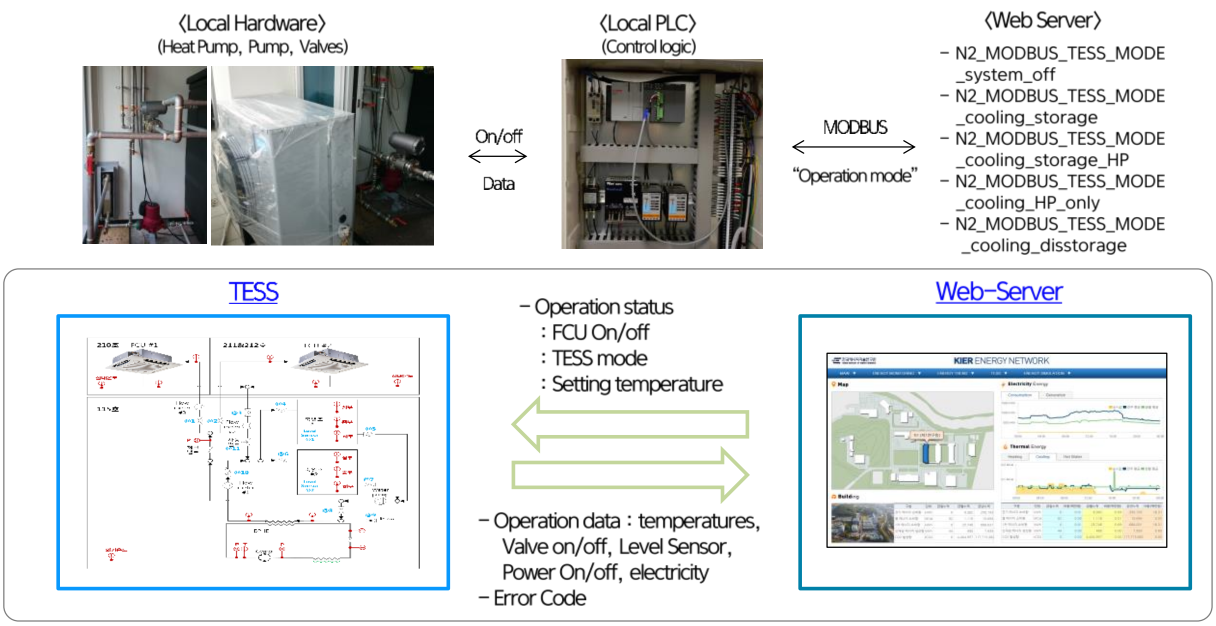

Figure 4. Design concept of communication layout for TESS

4. Results of demonstration operation

Absorption chiller heater is the main cooling facility of KIER. The COP based on primary energy usage is 1.04. This value corresponds to COP of 2.6 based on electricity energy when the power generation efficiency is assumed as 0.4. TESS consumes electricity for not only heat pump but also auxiliary devices (circulation pump, automatic valves). System COP considering total electricity consumption is needed to evaluate improvement compares to conventional system. The demonstration results of July 2016 showed COP 3.88 of heat pump only. This value corresponds to 3.39 of system COP. During the August operation, the starting time of heat storage was moved to mid night. This made the increase of average heat pump system (COP 4.08). Therefore the system COP became 3.56. Compared to the absorption chiller heat system installed, the TESS showed 30% improvement for July and 37% for August.

Table 4. Cooling operation results of demonstration operation for July and August 2016

July			August		
Date	**Heat pump COP**	**System COP**	**Date**	**Heat pump COP**	**System COP**
2016-07-05	3.36	2.94	2016-08-01	3.41	3
2016-07-06	4.22	3.67	2016-08-02	2.7	2.37
2016-07-08	4.02	3.51	2016-08-03	3.11	2.71
2016-07-09	2.91	2.55	2016-08-04	3.68	3.23
2016-07-10	3.71	3.24	2016-08-05	3.3	2.88
2016-07-11	3.6	3.12	2016-08-09	5.03	4.36
2016-07-12	4.06	3.56	2016-08-10	3.92	3.41
2016-07-13	4.14	3.61	2016-08-11	3.86	3.4
2016-07-14	3.97	3.49	2016-08-12	3.45	3.01
2016-07-16	3.89	3.38	2016-08-16	3.43	2.91
2016-07-18	4.35	3.78	2016-08-17	4.65	4.04
2016-07-19	3.27	2.87	2016-08-18	4.04	3.53
2016-07-20	3.76	3.28	2016-08-19	4.35	3.78
2016-07-21	3.1	1.79	2016-08-20	5.06	4.43
2016-07-26	4.78	4.16	2016-08-21	5.33	4.66
2016-07-27	3.63	3.2	2016-08-22	4.26	3.7
2016-07-28	3.85	3.38	2016-08-23	4.34	3.79
			2016-08-24	4.68	4.06
			2016-08-25	4.74	4.07
			2016-08-26	4.17	3.65
Average	**3.88**	**3.39**	**Average**	**4.08**	**3.56**

Load shifting ratio is also important performance index of TESS. The reference peak load is required for the calculation. On 8th August, operation to measure reference cooling load was performed by stopping operation of TESS. Ultrasonic flow meter was installed in fan coil units. The accumulated heat was calculated using mass flow rate and inlet/outlet temperature difference. The measured thermal load of that day was 15.6kWh.

Considering daily variation, the reference value was determined as 18.7kWh which is 20% higher than the measured value. Load shifting ratios was calculated for Tuesday and Wednesday of the third week of August. Total heat release from TESS was 12kWh on Tuesday and 11.1kWh for Wednesday. Therefore load shifting ratios were 64% and 59% respectively.

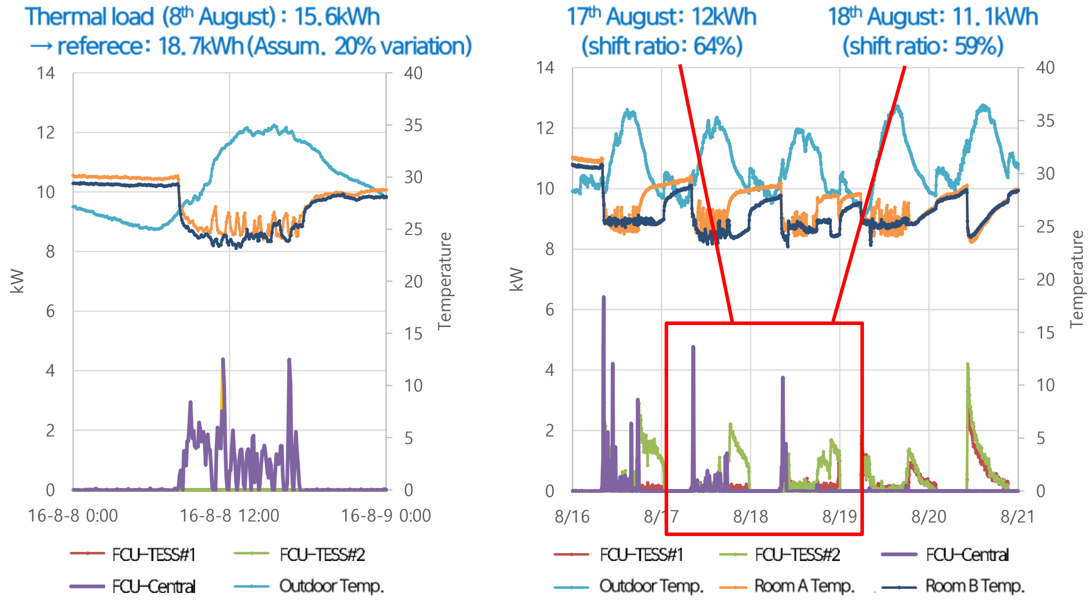

Figure 5. Demonstration operation for evaluating load shift potential of TESS

5. Concluding Remarks

To reduce peak load demand of summer season, thermal energy storage system (TESS) was selected. The main cooling device of KIER is absorption chiller heater which has COP 1.04 based on primary energy consumption (COP 2.6 based on electricity). Phase Change Material (PCM) was applied to store thermal energy in order to increase energy efficiency and energy density. TESS was designed to change operation modes through web-server. Considering wide applications, communication layout was designed. Pilot system was installed to deal with cooling load of two offices in KIER. The results of demonstration operation during the summer season of 2016 showed that the system COP of TESS was over 30% higher than main cooling devices.

Acknowledgements

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