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Prediction-Based Midterm Operation Planning for Energy Management of Exhibition Hall

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Abstract**—**Large exhibition halls require a lot of energy to maintain comfortable atmosphere for the visitors viewing inside. One way of reducing the energy cost is to have thermal energy storage systems installed so that the thermal energy can be stored in the middle of night when the energy price is low and then used later when the price is high. To minimize the overall energy cost, however, we should be able to decide how much energy to save during which time period exactly. If we can foresee future energy load and the corresponding cost, we will be able to make such decisions reasonably. In this paper, we use machine learning technique to obtain models for predicting weather conditions and the number of visitors on hourly basis for the next day. Based on the energy load thus predicted, we build a cost-optimal daily operation plan for the thermal energy storage systems and cooling and heating facilities through simulation-based optimization.

Keywords**—**Building energy management, machine learning, simulation-based optimization, operation planning.

I. Introduction

LARGE exhibition halls are places where a lot of people come to view great things. Since many people are in the exhibition hall during the exhibition time, the inner exhibition hall should be kept in comfortable atmosphere. To make comfortable atmosphere, air temperature, humidity and carbon dioxide should be maintained within a certain range. Large exhibition halls make it by installing chiller and heater. These machines handle the cooling and heating loads using gas or electricity. Cooling and heating load is a measurement of how much cold and heat are required in given space to maintain comfortable atmosphere. In summer and winter, the difference between the outside air temperature and the inside air temperature increases, so the cooling and heating load also increases. For these reasons, large commercial buildings such as exhibition halls consume a large amount of electricity and gas. This causes a lot of utility bill and environmental pollution. To prevent this, many developed countries are carrying out various building energy management policies. The government of the Republic of Korea recommends the installation of thermal energy storage system for large commercial buildings. The thermal energy storage system stores thermal energy in a thermal tank by running chiller and heater during night time when energy price is cheapest and uses thermal energy stored in day time when energy price is expensive. Using this characteristic of the thermal energy storage system, we will be able to save exhibition hall's energy consumption and utility bill. However, if less thermal energy is stored during night time, chiller and heater often operate in day time when energy price is high. On the contrary, if excess amount of thermal energy is stored, all thermal energy cannot be consumed in day time. These cases accelerate exhibition hall's energy cost.

To minimize the energy cost, how much thermal energy to store and how much to use is determined. If we can foresee the heating and cooling load and energy consumption depending on weather and visitors during the exhibition period, we will be able to determine when thermal energy storage system is used.

In this paper, we use a machine learning algorithm to model weather and visitors to estimate the heating and cooling load and energy consumption. Based on these estimates, we create on and off operation plans for optimal cooling and heating equipment on a daily basis using genetic algorithm in EnergyPlus, a building energy simulation tool.

Numerous researchers have studied building energy management. A study applied dynamic optimization techniques to control thermal energy storage system and cooling system [1]. Another study presented an overview of results and future challenges related to temperature control and cost optimization in building energy systems. Control and economic optimization issues are discussed and illustrated through simulation examples. The study concluded with results from model predictive control solutions and identification of important directions [2]. Reference [3] described the application of predictive control strategies to energy systems in small sized building and proposed MPC algorithms. Reference [4] was to find a solution to turn on and off the HVAC system of an office building using genetic algorithms to plan for a comfortable environment while reducing energy consumption.

II. Virtual Environment

We will first describe the exhibition hall and the heating and cooling system we target. Our exhibition hall is a large space with 126 m * 90 m * 15 m = 170,100 m^3. To handle the temperature, humidity and carbon dioxide of such a large area, exhibition hall is equipped with an air handling unit (AHU), which controls air quality, and a chiller/heater and generates cold and warm air.

The exhibition hall's cooling and heating system supplies cold and warm air using water. When heating is needed, hot water is supplied from the district heating system to the AHU internal water coil, and when cooling is necessary, cold water is generated by the absorption chiller using gas and a centrifugal chiller using electricity, an ice storage stores cold energy for the water coil. The system is as follows.

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To apply the mid-term plan, it is necessary to construct a virtual exhibition hall. In this paper, we will construct a virtual exhibition hall using EnergyPlus. Energy Plus is a simulation program to analyze building energy and thermal load. Based on the user's representation of the building's exterior walls, floors, windows, doors, and HVAC systems, Energy Plus calculates the heating and cooling load to maintain comfortable atmosphere defined by user and calculates the energy consumption of the heating and cooling system consumed according to the loads, and displays it to the user [5].

The virtual exhibition hall configuration in Step 1 is the defined appearance of the exhibition hall. We divided the area into a range of accommodating grid because multiple AHUs must be used to handle a single large hall. This can be easily implemented using the sketch-up tool.

Step 2, the building materials of the exhibition hall should be defined. EnergyPlus reflects the internal temperature thermodynamically according to the heat transmitted to the building wall, floor and roof. This can be easily implemented using the OpenStudio tool. The exhibition hall's building materials are as follows.

Step 3, The exhibition hall's cooling and heating system should be defined. According to Fig. 1, the AHUs, the chillers, the district heating, and the ice storage system are implemented using the OpenStudio tool.

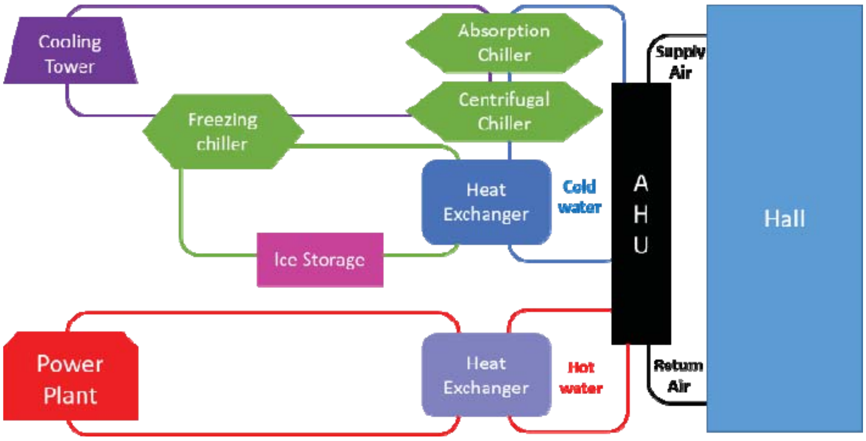

Fig. 1 Cooling/heating System of the exhibition hall

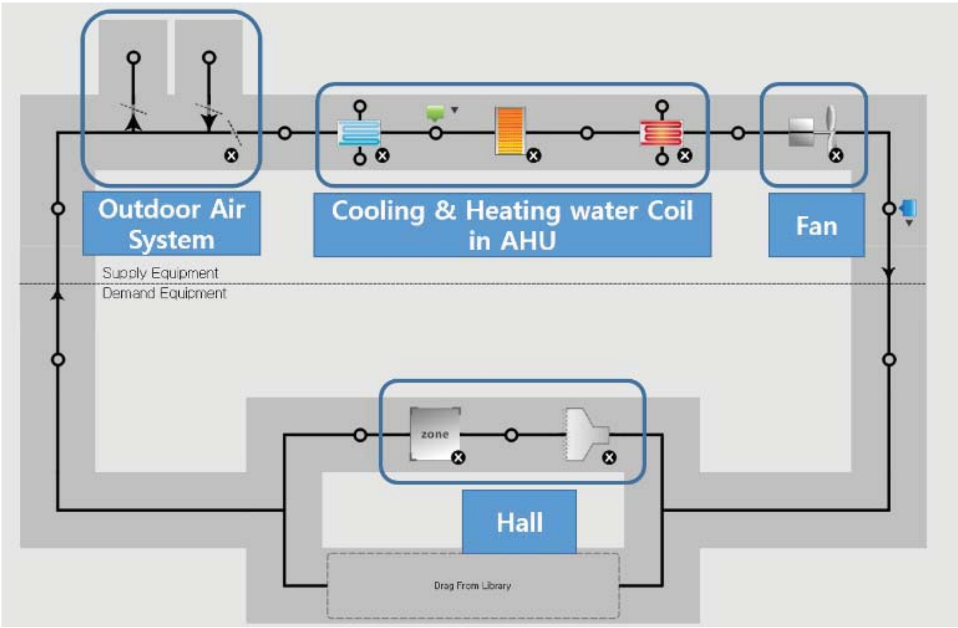

Fig. 2 Definition of AHUs using OpenStudio

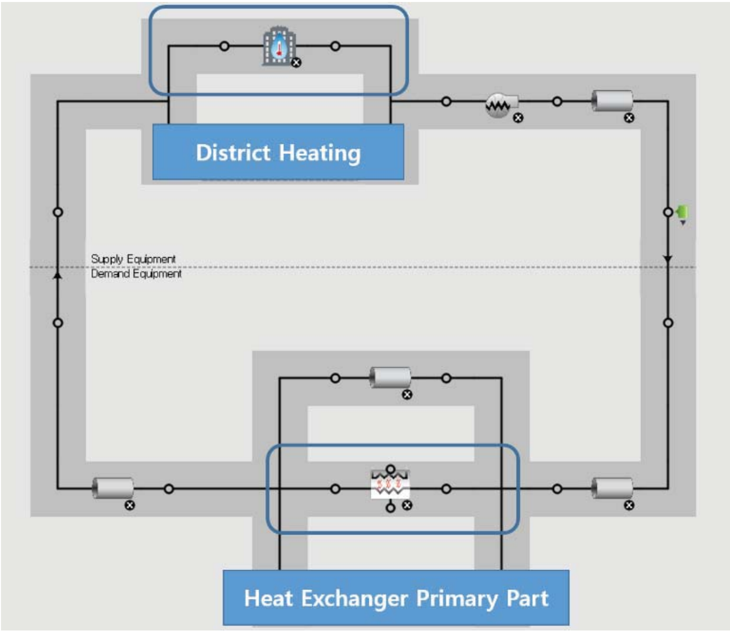

Fig. 3 Definition of district heating system using OpenStudio

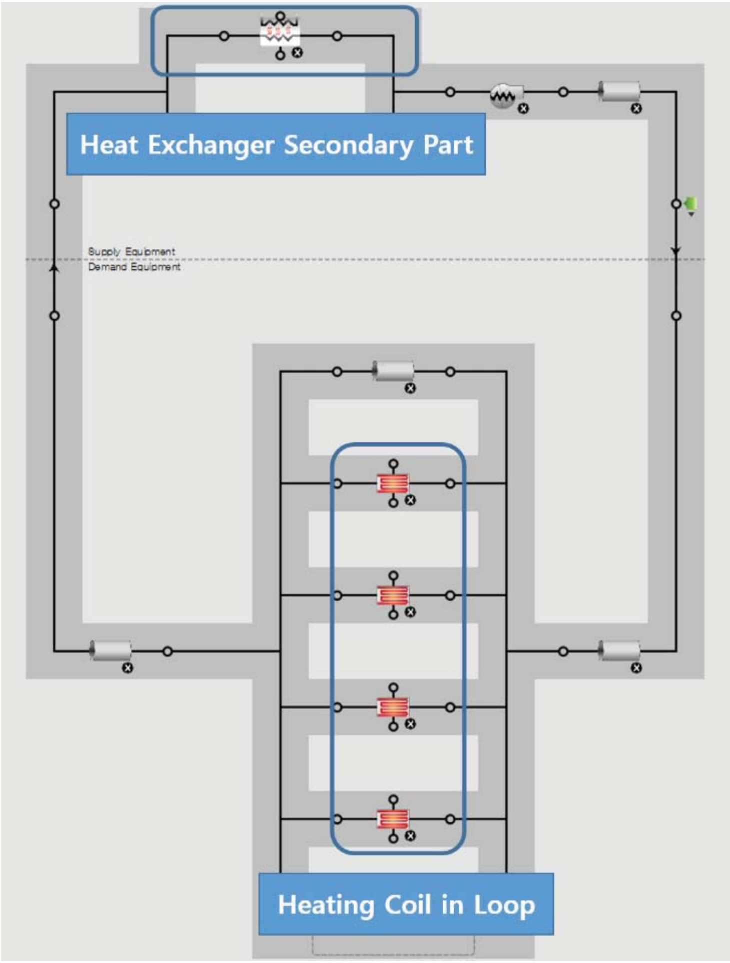

Fig. 4 Connection of hot water coil using OpenStudio

TABLE I
BUILDING MATERIALS

Type	Material	Thickness mm	Conductivity kcal/mh°C	Resistance m3h°C/kcal
Roof	Steel sheet	0.0007	46	-
	Air gap	0.050	-	0.10
	Gypsum board	0.011	0.18	0.06
	Air gap	0.050	-	0.10
	Insulator	0.125	0.033	3.79
Wall	AL panel	0.004	-	0.00
	Insulator	0.075	0.032	2.34
	Air Gap	0.050	-	0.10
	Gypsum board x2	0.0125	0.15	0.08
Floor	Granite	0.020	2.8	0.01
	Cement mortar	0.060	1.2	0.05
	Concrete slab	0.250	1.38	0.18
	Insulator	0.100	0.032	3.13
	Concrete	0.050	1.38	0.04
	Compaction rubble	0.200	1.15	0.17

In defining AHU step, an outdoor air system for supplying outdoor air, a water coil for supplying cold and warm air, a humidifier for humidity control, and a fan for air supply and exhaust should be defined. In defining heating system step, a district heating system, a heat exchanger and AHU's water coil should be defined so that plant's hot water is supplied to the exhibition hall. In defining cooling system step, an absorption chiller, a centrifugal chiller, a freezing chiller and an ice storage tank should be defined and connected to the AHU's water coil. By the above three steps, a virtual exhibition hall can be made and we can apply mid-term plan to reduce energy cost.

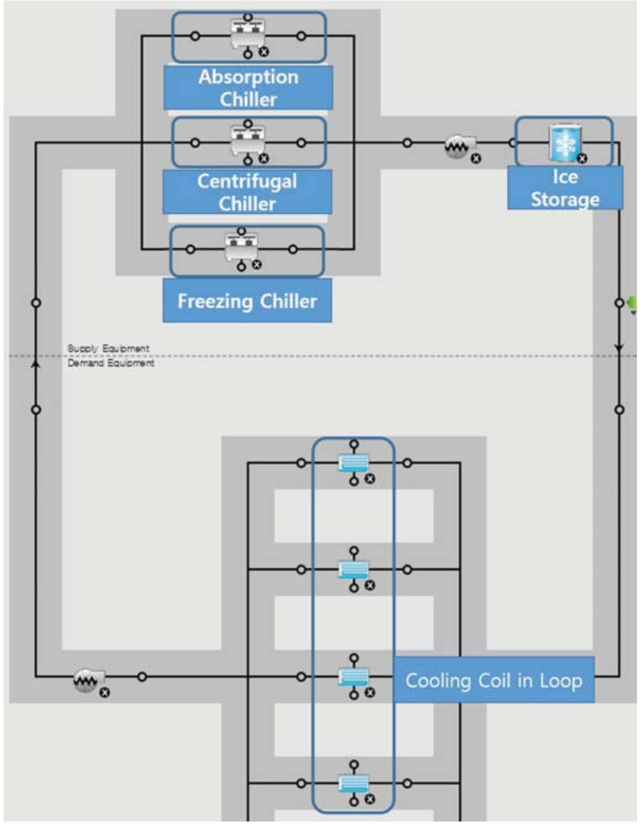

Fig. 5 Definition of chillers and ice storage tank using OpenStudio

III. WEATHER AND VISITORS PREDICTION

The inner atmosphere of the exhibition hall changes according to the weather and visitors. In the summer, when the outside temperature or the number of visitors is high, the internal temperature increases, resulting in a high cooling load. In the winter, a low external temperature and a low number of visitors causes a high heating load.

To achieve effective cooling and heating operation with a limited cooling capacity in ice storage, it is necessary to predict the external weather and number of visitors to estimate when high load is occurred inside the exhibition hall. In this paper, we make a model for predicting the external weather and the number of visitors for the load estimate computation using a machine learning algorithm.

In the weather predicting model, we make model for predicting the next day's weather based on the difference between the predicted data and the actual recorded data of previous day. The predicted model of humidity and carbon dioxide is the same as the temperature model.

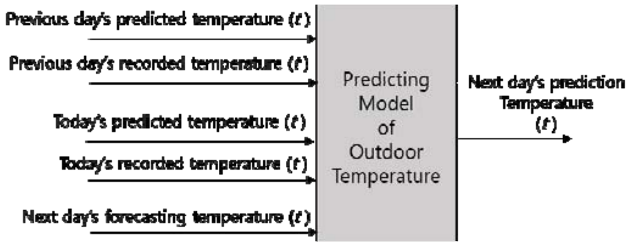

Fig. 6 Model of temperature prediction

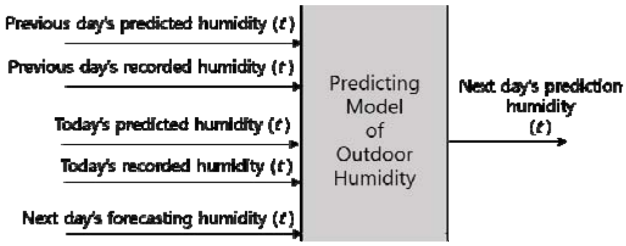

Fig. 7 Model of humidity prediction

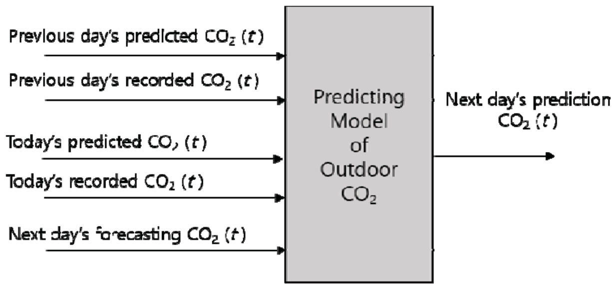

Fig. 8 Model of carbon dioxide prediction

In the number of visitor prediction model, number of people will be estimated by reflecting the pre-booking tickets and the error rate according to the size of the exhibition.

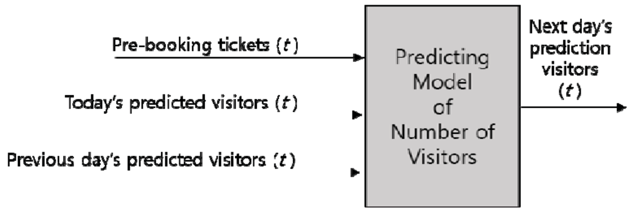

Fig. 9 Model of visitors prediction

IV. Mid-term Operation plan

In this paper, the mid-term operation system of the exhibition hall plans to minimize the total power consumption while providing a comfortable atmosphere by turning on and off the chillers, heater and ice storage. We solve this by using a genetic algorithm.

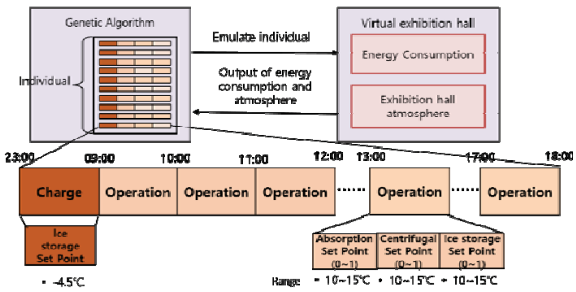

Fig. 10 Representation of genetic algorithm for mid-term plan

At each step of the optimization process, the best individuals are selected from the current population (the initial population is generated randomly) and serve as parents to produce children for the next generation. Selection is based on performance (typically, the genetic algorithm is more likely to select parents with better fitness values), which is why the thermal behavior of the four considered zones (z1, z2, z3, z4) in the hall is simulated for each individual in the population. Over successive generations, the population evolves toward an optimal solution allowing both the consumption of electricity in the zones to be minimized, and the thermal constraints to be met (temperature: 24°C, humidity: 50%, carbon dioxide: 1000 ppm).

V. Conclusion

In this paper, we propose a prediction-based mid - term operation planning system to reduce the energy costs of a large exhibition halls equipped with a cooling and heating system.

We explained how to construct a similar exhibition hall using EnergyPlus and how to construct a weather and visitor prediction model to estimate the time of high heating and cooling load. Finally, to determine when to run the chiller and heater, it is necessary to express the on and off functions of the equipment as a solution and to repeatedly perform the selection, the crossover and the mutation operations to obtain the optimum equipment operation plan that considers low energy consumption and a comfortable atmosphere. Therefore, if the system is developed and applied, energy costs are expected to be reduced by at least 5%. In the future, existing exhibition hall operation plans will be compared with the plan made by the proposed system.

VI. Acknowledgment

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