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Development of operational guidelines for thermally activated building system according to heating and cooling load characteristics

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HIGHLIGHTS

- Operation guidelines for TABS by considering the building load characteristics were suggested.
- Operation guidelines can be used by field technicians other than automatic control system.
- Comfort criteria and surface condensation risk during TABS operation were considered in operation guidelines.
- The building load characteristics were analyzed through the dynamic energy simulation.
- Thermal output from TABS were estimated through the thermal simulation.

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ABSTRACT

Since the end of the 1990s, thermally activated building systems (TABSs) have emerged as an energy-efficient and economically viable means of heating and cooling buildings. Because the temperature of the water that these systems use is very close to room temperature, TABSs are one of the most energy- and exergy-efficient types of heating/cooling systems. However, because TABSs have a high thermal inertia and respond only slowly to control inputs, it is very difficult to maintain the room air temperature within a narrow control band. Control methods and operational strategies have been the main concerns of previous studies. There is a limit to the thermal output that a TABS can provide, owing to the possibility of surface condensation forming and possible thermal discomfort of the occupants. Thus, carefully considered operational strategies and use guidelines are necessary when applying such systems. This study focuses on the development of operational guidelines for TABSs according to the heating and cooling load characteristics of a specific campus building. The load characteristics of the building were analyzed, after which load zones were defined according to the heating and cooling characteristics. Simultaneously, the thermal output of a TABS for heating and cooling was calculated with a range of supply water temperatures. Operational guidelines are suggested, classified by load zone.

1. Introduction

A thermally activated building system (TABS) makes use of a building's thermal mass with the installation of embedded piping. Generally, the high thermal inertia of the concrete used in the construction of a building helps to create an optimal indoor climate and minimizes the amount of energy consumed for heating and cooling. A TABS can work in conjunction with heating and cooling sources at temperatures close to room temperature, which increases the energy efficiency of heating and cooling sources such as heat pumps, condensing boilers, solar collectors, and in-ground heat exchangers. Additionally, a TABS can reduce the peak heating/cooling energy consumption by exploiting the concrete's high thermal inertia. As TABSs are often operated asynchronously with the heating/cooling loads of the building, some parts of the heating and cooling load can be shifted from daytime to nighttime, resulting in a reduction in the initial cost of the plant as the capacity of the HVAC system can be reduced. In terms of building construction, floor heights can be reduced as duct sizes can be reduced, eliminating the need for suspended ceiling panels. In this way, it is possible to lower the initial and operation costs relative to conventional HVAC systems. However, the application of TABSs still presents some limitations and difficulties in terms of control and operation during the heating and cooling seasons. There is a limit to the thermal output of a TABS for cooling and heating because of issues with condensation and occupant comfort. When, during the cooling season, the surface temperature of a ceiling or floor

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Nomenclature

Q_{TABS}	TABS thermal output (W m^{-2})
c_p	specific heat of water (J kg^{-1} K^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
ΔT	temperature difference between the supply and return temperature (K)
HVAC	heating, ventilation, air-conditioning
TABS	thermally activated building systems
IAQ	indoor air quality
T	temperature

Subscripts

dew_i	indoor dew-point temperature
limit_cooling	start time for cooling operation
limit_heating	start time for heating operation
o_max	maximum outdoor air
o_min	minimum outdoor air
sf	surface temperature
sf_max	maximum surface temperature
wr	return water temperature
ws	supply water temperature

in which TABS pipes are embedded is lower than the dew point temperature of the indoor air, surface condensation can be formed. Careful operational strategies and the application use of guidelines are necessary to apply such systems, taking boundary conditions and dynamic system behavior into account.

These limitations on the operation of a TABS are dependent on the local weather conditions (such as the outdoor air temperature and humidity) and the load characteristics of the building. In hot and humid summer weather conditions such as those in Korea, TABSs should be used for cooling with consideration given to surface condensation. Additionally, because TABSs are not as common in Korea as they are in Europe and North America, basic TABS operational guidelines based on the building load characteristics have yet to be developed. Therefore, this study focuses on the development of operational guidelines for a TABS installed in a campus building in Seoul, Korea. In conclusion, operational guidelines that are suited to the heating and cooling load characteristics of this building are suggested. First, the load characteristics of the building were analyzed, after which the load zones were characterized according to the characteristics of the heating and cooling loads. Simultaneously, the thermal output of the TABS was calculated for heating and cooling with a range of supply water temperatures. The PHYSIBEL software was used for the thermal simulation. As a result, operational guidelines classified by load zone are suggested.

2. Current status of TABS control and operation

2.1. Literature review of TABS control and operation

Recently, building technologies have focused on energy efficiency and potential energy savings as part of the effort to reduce greenhouse gas emissions. Additionally, energy policy places a high priority on energy saving in buildings and the use of renewable energy. In Europe, ambitious targets have been set to ensure that all new buildings consume very little energy, with the BPIE announcing that all new buildings built by member states after 2020 must be “nearly zero-energy building” [1]. Thus, low energy consumption has become a top priority in new building design and renovation. There are many technologies that have the potential to improve energy efficiency in buildings; in terms of innovative cooling and heating technologies and their operation strategies [28,32–36]. In recent years, the improved performance of building envelopes through the use of high-performance insulation and high-performance windows has reduced heat transmission and infiltration losses, thus reducing energy use. Also, researches about application of the PCM (phase change material) have been conducted to improve building’s thermal mass and effective control of indoor environment [30,31]. It is well known that the amount of energy consumed for heating and cooling can be reduced by the installation of radiant heating and cooling systems [2]. Some researches about a radiant system for heating and cooling of a building have been conducted and showed the efficiency of these systems [38–41]. For this reason, the end of the 1990s saw the appearance of TABSs in Europe as an energy-efficient and economically viable means of heating and cooling [3–6]. In Europe, the application of TABSs to different types of buildings, including office buildings, schools, museums, and other commercial buildings, was monitored and evaluated with respect to energy consumption, thermal comfort, and ease of operation [3,12]. With the results of these monitoring projects, theoretical studies could be verified and computer simulation tools, such as EnergyPlus and TRNSYS, validated [13–15,29,43]. Through energy simulation analysis, the potential of a TABS to reduce primary energy consumption and demand, as well as provide thermal comfort relative to conventional air systems, was confirmed [16,17]. Because these systems depend on circulating water at a temperature that is very close to room temperature, they are one of the most energy- and exergy-efficient types of heating and cooling system. However because TABSs have high a thermal inertia and can respond only slowly to control inputs, several control strategies have been studied [7–9]. Gwerder et al. [7] presented temperature control strategies for rooms with a TABS, considering the prediction uncertainty of heat gains during operation by specifying respective bounds. A pulse width modulation control module proved to be well suited to the intermittent operation of the TABS [8]. Additionally, the impact of the configuration and operation modes on the energy efficiency of a TABS was recently reported by Lehmann et al. [9]. Recently, Gayeski et al. [10,11] reported on the development and testing of a predictive TABS pre-cooling control algorithm that controls a low-lift chiller according to the TABS temperature response.

2.2. Current status of TABS operation in campus building

The surging consumption of energy in heating and cooling has led to an imbalance between electric power supply and demand in South Korea, causing nationwide problems such as massive blackouts during the peak heating and cooling periods of summer and winter. To mitigate such problems, it is necessary to develop HVAC technologies that can shift peak load. This could be done by leveraging time-lag effects as well as improving the energy efficiency of the buildings by integrating renewable and previously unused energy sources. TABSs have attracted the attention of Korean researchers [18]. Unlike in Europe and the USA, the application of TABSs is rare in Korea because of climate, cultural, and technical issues that must be overcome. As such, operational guidelines have not been developed for the application of TABSs during the heating and cooling seasons. Therefore, the development of operational guidelines for TABSs must be a priority. As part of this research, to understand the current status of TABS implementation in Korea, a field survey was conducted by interviewing field technicians,