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Integrating hollow-core masonry walls and precast concrete slabs into building space heating and cooling

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ABSTRACT

Hollow-core masonry block walls and precast concrete slabs can be used for active thermal energy storage to assist space heating and cooling by circulating air through their hollow-core space. This Building-Integrated Thermal Energy Storage (BITES) approach can provide a significant amount of effective mass for relatively fast thermal energy storage and release. Furthermore, it integrates several building functions into one building fabric component. Hence, it can significantly improve buildings' thermal performance while saving overall cost and room space. This study explains the benefits of using ventilated BITES systems, such as effective use of materials and enhanced thermal performance. The characteristics and thermal performance of three system configurations that have airflow to zone are presented. These three configurations can significantly enhance the thermal coupling between a ventilated BITES and its zone, and hence can enhance the thermal performance of the zone. Qualitative and quantitative comparisons of thermal performances between different configurations with and without airflow to zone are presented. This study also investigates a practical approach for applying ventilated BITES in buildings-using standard hollow-core masonry blocks and precast concrete slabs. The thermal properties of these standard construction units and their potential variations are investigated, and some design considerations are presented. The walls and slabs of interest include structural or non-structural masonry block walls and structural precast concrete slabs.

1. Introduction

Thermal Energy Storage (TES) systems such as ice or water tanks, ground storage, and thermally massive walls and slabs, have been widely used in building applications [1,2]. The thermal energy stored in TES systems needs to be released to occupied space in an appropriate manner (e.g. rate and location) to moderate its mechanical space conditioning (i.e. heating or cooling) demand [3,4]. Effective TES systems with proper operations can significantly improve the thermal performance of buildings. The improvements include enhanced thermal comfort by reducing room temperature fluctuations, higher efficiency and smaller capacities of mechanical equipment (e.g. chiller, air ducts), reductions of peak demand and energy procurement from utilities, more effective utilization of renewable thermal energy, and offsetting the mismatch of demand and different energy supplies [5-8].

Building fabric (i.e. structure skeleton, partitions, and envelope) constitutes a significant portion of a building's thermal storage capacity. Braun [9] stated that the thermal storage capacity of a typical concrete building is in the order of 0.1 kWh/K per m^2 of gross floor area, equivalent to that of a 0.2 m thick concrete slab. The normal thickness of concrete slabs ranges from 0.15 to 0.4 m [10,11]. Due to masonry and concrete's long term chemical and physical stability, fire resistance, and availability of raw materials, they are among the world's most widely used building materials. These characteristics promote concrete and masonry building fabric as effective means for TES in a wide range of buildings. Using building fabric for TES can be referred to as Building-Integrated Thermal Energy Storage (BITES).

Given BITES' high thermal storage capacity, it can absorb and release significant amount of thermal energy from and to its zone to modulate the zone temperature [3,12,7]. Successful modulation requires sufficient thermal coupling between BITES and the rest of its room [13]. BITES with exposed room side surfaces inherently has strong thermal coupling with its zone due to its large surface area. Therefore, for space conditioning loads with moderate amplitudes, simply exposing the surfaces of walls and floors (i.e. passive BITES) will create sufficient thermal coupling. Passive

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Nomenclatures

$Ratio_{cr}$	area ratio of core surface to room-side surface
AHU	air handling units
BITES	Building-Integrated Thermal Energy Storage
PID	proportional, integral and derivative
TES	thermal energy storage

BITES has been widely applied [9,14,15]. However, when amplitudes are high, such as passive solar heating on a cold and clear winter day, stronger thermal coupling is needed so that more thermal energy can be stored and released timely [8,13,16]. Furthermore, stronger thermal coupling increase the effective use of thermal storage mass, since heat can penetrate deeper into BITES' core area.

Alongside passive BITES, active BITES have also attracted significant research interest [1,4,7,8,17–19]. Charging systems of active BITES are normally embedded into building fabric. These systems can be hydronic, air-based (i.e. ventilated) or electric. The advantages of using active BITES include the following:

- Internal active charge engages core storage mass for heat exchange. Together with charge on the exposed surfaces, they result in larger effective storage mass and heat exchange area. Hence, faster and larger thermal energy storage/release is possible when needed. They promote the utilization of renewable energy that is only available intermittently and/or of low-grade (i.e. solar energy, nighttime cool air) [18];
- Energy from detached sources, such as ground heat and thermal energy collected by solar devices, can be stored in the BITES through heat transfer fluids;
- Active charge improves the control of charge/discharge. The BITES temperature, heat transfer rate, and amount of storage can be controlled more easily than that of passive systems;
- Instead of acting passively, active BITES can be used to regulate the zone temperature proactively, like large radiant panels with significant thermal storage mass [20];
- Larger thermal storage capacity and more controllable charge/discharge result in better demand-side management than passive BITES [4];
- Using active BITES, savings in room space and construction (material and installation) can be achieved in comparison with conventional centralized and thermally isolated storage systems (e.g. water/ice tanks).

Building fabric components that have hollow cores, such as hollow core slabs and concrete masonry block walls, can be easily used as ventilated BITES systems by connecting their hollow cores to form air channels (Fig. 1). Air as heat transfer fluid is circulated through the air channels to charge and discharge the core mass of the BITES systems. If room space is part of the air circulation path (the options of having return and/or supply air into zone as shown in Fig. 1), this type of BITES system can be referred to as ventilated BITES with airflow to zone. In addition to the above mentioned advantages, one unique advantage of ventilated BITES with airflow to zone is that stronger thermal coupling between the BITES and the rest of the room can be provided. This advantage will be further explained in the next section. The air channels can be used as ventilation ducts. Wires and pipes can also be incorporated in them. By eliminating the conventional space required for service systems, the floor-to-floor height will be reduced. Hence, the possibility of having additional floors for a given permitted building height is increased.

BITES systems combine thermal and building fabric/structural functions. These functions share some common design parameters, such as the overall thickness and the hollow core diameter. Therefore, the designs of these functions interact with each other. Take a concrete slab for example, larger hollow core diameter increases the heat transfer area between the core air and the cores, but it reduces the net cross sectional area and hence reduces the shear strength of the slab. In order to take full advantages of BITES systems, i.e. offer multiple functions with effective use of the material and the architectural space, an integrated design is needed. In current research and development activities, there exists a disconnection between structural and thermal designs. Methodology and guidelines for the integrated design of ventilated BITES systems are needed [20].

Ventilated BITES can provide a significant amount of effective mass for relatively fast thermal energy storage and release. Compared to BITES without airflow to zone such as hydronic floors, ventilated BITES with airflow to zone can significantly enhance the thermal coupling between a BITES and the rest of its room. These

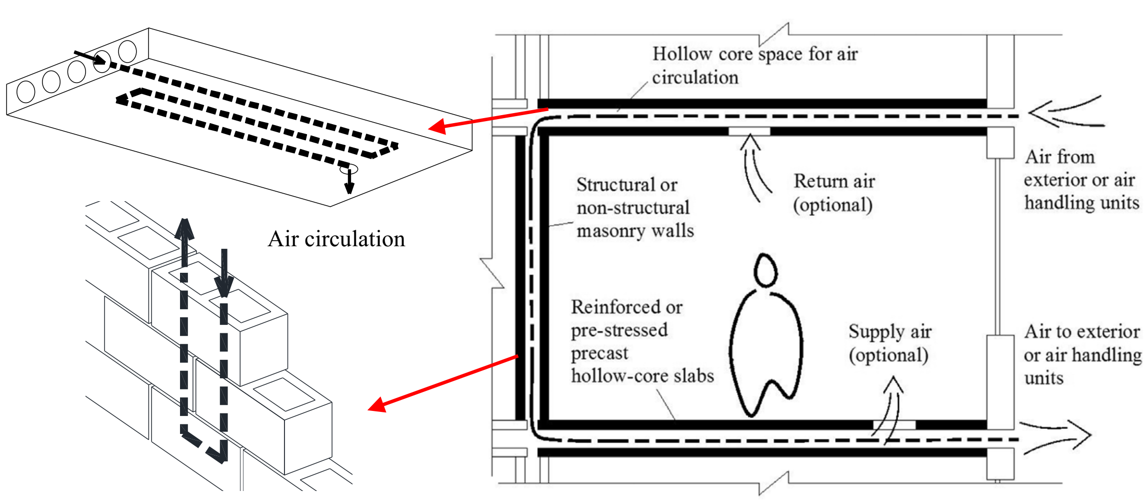

Fig. 1. Scheme illustrating use of hollow-core walls and slabs for ventilated BITES (connections between walls and slabs are optional).