Thermal Active Building Systems (TABS): A Path to Energy Flexibility and Renewable Integration

Key words: Thermal Active Building Systems (TABS); energy flexibility; renewable integration; demand response; building energy systems

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This article presents the use of Thermally Activated Building Systems (TABS) to leverage building thermal mass in enhancing energy flexibility, load shifting, and reducing energy consumption. It highlights TABS' integration with renewable energy sources and the role of control strategies in optimizing TABS for real-world applications, especially in settings with fluctuating energy supplies.

With the shift toward sustainable energy, TABS have emerged as a key approach in reducing the building sector's environmental footprint. Buildings account for about 30-40% of global energy demand and nearly 40% of CO_2 emissions [1]. Systems like TABS help in optimizing energy use by utilizing thermal mass for efficient heating and cooling.

A unique characteristic of TABS is its ability to operate at low heating and high cooling temperatures, which aligns well with renewable sources such as geothermal or solar thermal energy. Studies show that when coupled with renewable energy sources, TABS can reduce peak load demands by 15-20%, enhancing grid reliability [2]. The present paper examines TABS' functionality, benefits, challenges, and future outlook, emphasizing its role in sustainable energy systems.

Thermal Active Building Systems (TABS)

Thermally Activated Building Systems use a building's concrete slabs as thermal mass to store and release energy slowly, reducing temperature fluctuations and maintaining indoor comfort. The slow response time of TABS is offset by their energy-saving potential, as they can capture excess heat or cold, releasing it during peak demand periods. TABS can reduce heating and cooling energy demands by as much as 30-50% under optimal operation conditions, significantly lowering operational costs [3]. For instance, a TABS setup in an office building in Denmark showed 17% energy savings during summer cooling seasons [6]. However, the delayed thermal response of TABS can lead to discomfort if not managed with a suitable control system, especially in climates with significant temperature swings [4]. Additionally, TABS requires a balance between insulation, ventilation, and humidity controls, which can complicate design considerations [5].

Energy Flexibility using TABS

Energy flexibility is crucial as renewable energy sources become a larger share of the energy mix. TABS allows buildings to act as 'thermal batteries,' storing and releasing energy according to supply conditions, which is essential for balancing renewable generation with demand [4]. Studies indicate that TABS can shift up to 35% of a building's daily load to off-peak hours, reducing energy costs and peak demand [5].

A zero-energy office building with TABS in China demonstrated an 8.13 Wh/m² energy reduction during peak hours and a 23.53 Wh/m² increase during off-peak periods, highlighting TABS' role in flexible demand management [7]. Integrating TABS with demand-side management (DSM) strategies allows for efficient load shifting based on real-time energy prices and demand, reducing grid reliance during peak times. Simulations suggest that TABS in residential buildings can achieve a 20-30% cost reduction through DSM, especially when coupled with adaptive controls that respond to variable tariffs and grid signals [4, 6].

Energy Savings and Renewable Energy Integration

TABS not only enhances energy savings but also increases compatibility with renewable sources. Buildings using TABS for heating and cooling can integrate with low-temperature geothermal or solar thermal systems to maintain indoor climates effectively and sustainably. The capacity of TABS to operate at low temperatures makes them ideal for renewable integration. For example, geothermal systems operating at 30-50°C can meet the heating requirements of TABS efficiently, reducing fossil fuel reliance by 15-25% [3]. Additionally, TABS' ability to store and shift energy can reduce operational costs significantly. Research shows that buildings equipped with TABS can reduce annual energy costs by 15-40% compared to conventional systems, particularly when using variable pricing [2, 5]. For instance, in an urban case study, energy costs were reduced by 21.3% when flexible heating schedules with TABS were implemented [2, 6].

TABS uses the building mass to store and release thermal energy, allowing renewable energies to be optimally integrated. Solar power generated during the day can be stored directly within the building mass and released at night, facilitating effective load shifting. This capability reduces grid dependence and bridges supply bottlenecks. At the same time, TABS enable peak shaving by absorbing excess energy when it is available and thus avoiding peak loads. This function not only alleviates stress on the electricity grid but also helps to minimize grid expansion costs—a critical consideration as the transition from fossil fuels to electricity-based heat pumps accelerates. By reducing grid loads and enhancing energy flexibility, TABS makes buildings grid-friendly and future-ready, supporting the shift towards a more sustainable energy landscape.

AktivDHKS is an external wall temperature control system developed in Germany and is a TAB. A simulation study was carried out for one building, in which ActiveDHKS was compared with conventional refurbishment options such as ETICS and radiators as well as ETICS and underfloor heating to evaluate possible advantages and disadvantages. **Table 1** shows that the AktivDHKS system has lower electricity requirements compared to the radiator variant but higher requirements than the underfloor heating variant. The degree of self-consumption, i.e. the ratio of self-consumed PV electricity to the electricity demand of the heat pump in the heating mode (excluding cooling), was increased by approx. 9 % compared to the radiators and as much as 13 % compared to the underfloor heating system when using the AktivDHKS (**Table 2**) [9].

Table 1. *Comparison of electricity purchase and own use. Electricity requirement of the heat pump without cooling (kWh).*

System Type	Grid Reference (kWh)	Own-Use (kWh)	Feed-In (kWh)
AktivDHKS	1471	1545	25527
Underfloor Heating	1428	867	26205
Radiators	2123	1551	25520

Table 2. *Comparison of electricity purchase and degree of owner-occupancy. Electricity requirement of the heat pump without cooling (kWh).*

System Type	Demand (kWh)	Own-Use (%)
AktivDHKS	3016	51,2%
Underfloor Heating	2294	37,8%
Radiators	3674	42,2%

Figure 1 depicts the structural design of the AktivDHKS system solution. The AktivDHKS system solution integrates advanced technologies to enhance energy efficiency and performance in buildings. At its core, it utilizes Thermal Component Activation (TCA), where structural elements like walls, ceilings, or floors serve as thermal storage and energy delivery systems. This enables efficient heating and cooling by circulating water or other media through embedded pipes, leveraging the thermal mass to store and release energy.

The system incorporates insulation as well as heating and cooling function (DämmHeizKühlSystem – InsulationHeatingCoolingSystem - DHKS) to provide localized heating and cooling but only the basic temperature control. Individual temperature control is achieved with existing radiators at a low temperature level. It also connects to renewable energy sources such as solar thermal panels and heat pumps, promoting energy self-sufficiency and reducing reliance on the grid.

Smart energy management algorithms further enhance the system's functionality by predicting energy demands based on occupancy patterns, weather forecasts, and energy prices. This dynamic control ensures real-time energy balance, increases flexibility, and optimizes resource use. The AktivDHKS system aligns with sustainability goals by reducing greenhouse gas emissions, integrating renewable energy, and supporting decarbonization in the building sector. This innovative approach positions the system as a key solution in achieving energy-efficient, comfortable, and environmentally friendly buildings.

This reduces the load on the electrical grid accordingly. It should be noted that an optimized control system for maximizing self-utilization has not yet been implemented, indicating the potential for further improvement through enhanced control and regulation strategies in the reference house. This study investigated the activation of external walls (TABS) in an existing apartment building, comparing it with radiators, external thermal insulation composite systems (ETICS), and underfloor heating across various refurbishment scenarios. The results demonstrated that TABS is a grid-compatible solution, making it suitable for modern sustainable building applications.

Discussion

The growing need for energy flexibility has positioned TABS as a viable solution in modern sustainable building design. However, to realize their full potential, certain challenges need to be addressed. TABS require careful planning regarding the thickness of slabs, material properties, and insulation levels to avoid overheating or undercooling. A study showed that improved insulation can increase thermal storage

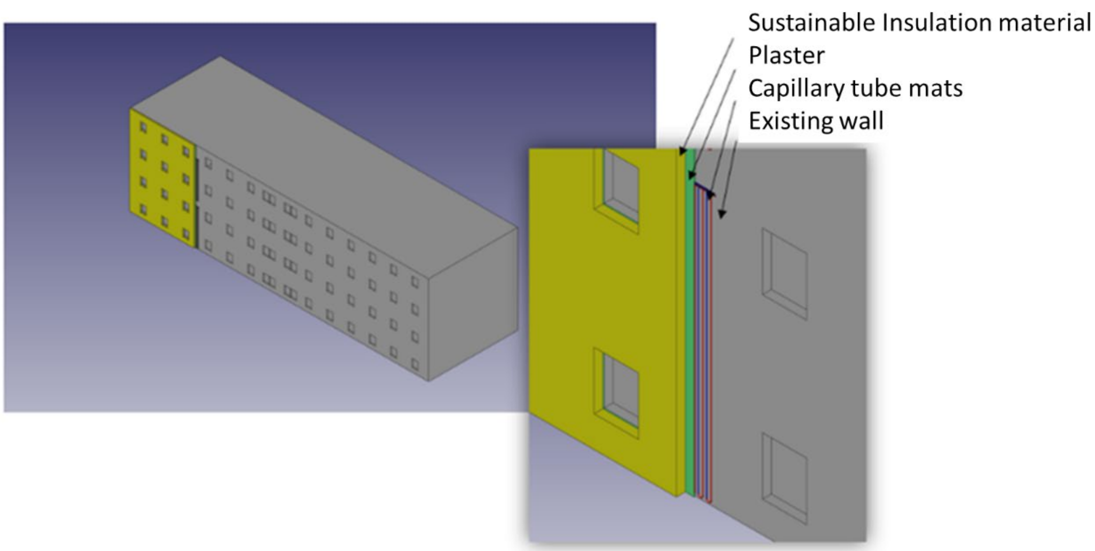

Figure 1. Structural design of the AktivDHKS system solution [10].

efficiency but may also raise the risk of overheating in summer if not managed with appropriate ventilation [4, 8]. The success of TABS in real-world applications hinges on control strategies. Rule-based, predictive, and adaptive control strategies have shown varying success. Advanced adaptive controls, such as Model Predictive Control (MPC), can improve efficiency by predicting energy use based on weather forecasts, occupancy patterns, and grid signals, achieving up to 40% greater efficiency than static controls [7, 8]. Research continues to explore the benefits of TABS in dynamic building environments. Emerging technologies like Artificial Intelligence (AI) and machine learning in predictive control systems are expected to maximize energy savings and comfort levels, potentially transforming TABS into core components of intelligent building energy systems [1].

Conclusion

TABS has proven to be an effective approach for improving energy efficiency, flexibility, and renewable energy compatibility in buildings. Their ability to act as thermal energy storage makes them a valuable asset in the shift toward grid-responsive and sustainable building designs. By optimizing control strategies and integrating TABS with renewable sources, buildings can contribute to a more balanced, low-carbon energy future.

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