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BTTAB – Broad-Based Testing of Energy-Efficient Demonstration Buildings with Thermally Activated Building Components

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Abstract. The expansion of renewable energy generation as well as extensive possibilities for energy storage are central cornerstones of the energy transition. Thermal building component activation can be a key aspect here, as it can be used multifunctionally as a heating and cooling delivery system and as a storage system for fluctuating renewables. These applications not only offer enormous potential for the integration of renewable energies and waste heat, but they also promise high economic attractiveness and impress with their simplicity in implementation, operation and use.

In order to investigate these properties of Thermally Activated Building Structures (TABS) on real buildings, in the study BTTAB [1] 18 demonstration buildings spread over Austria have been selected for monitoring and surveys. It is intended to provide information about the performance of the storage and energy flexibility potential on the one hand, and to generate essential findings with regard to user comfort, user satisfaction, economic aspects in construction and operation as well as functionality on the other.

This paper highlights the various applications of the thermal building component activation technology and provides already derived results relevant for the planning, design and operation of future buildings with TABS.

Keywords: Thermally Activated Building Components, TABS, Monitoring

1. Methodology

The first step was to select the demonstration buildings. The demonstration buildings differ not only in their type of use, but also in the application of TABS in combination with the energy supply concept. In the ongoing work of the BTTAB study, the differences are highlighted and contrasted with the monitoring results.

Table 1. *Overview of all demonstration buildings and TABS applied.*

Building Name	Utilisation	Heating and Cooling System	TABS
Steiner Haustechnik KG	Trading	Geothermal Heat Pump	Concrete ceilings
Tower Puchstrasse	Commercial, student housing	Groundwater: Heat Pump and Freecooling, Photovoltaics	Brick exterior wall
Haus der Generationen	Kindergarten	Groundwater: Heat Pump and Freecooling, Photovoltaics	Exclusively for cooling: Concrete ceilings
BOKU Türkenwirt building	University	Geothermal Heat Pump, Chiller, Waste heat, Solar thermal system, Photovoltaics	Concrete ceilings
Hörburger Römergrund	Production	Groundwater: Heat Pump and Freecooling, Photovoltaics	Concrete base plate
Office Forchtenstein	Office	Air Heat Pump	Concrete ceilings
MAM Forschungs- und Entwicklungszentrum	Research	Geothermal Heat Pump, Photovoltaics	Concrete ceilings
LITE GmbH	Office, Production	Geothermal Heat Pump, Waste heat	Office: Concrete ceilings, Storage: Concrete base plate
Krug	Residential	Geothermal Heat Pump	Concrete ceilings
Gugler Holding GmbH	Office, Production	Groundwater Heat Pump, Gas Boiler	Office: Concrete ceilings, Production: Concrete base plate
Rosthorngasse	Residential	Geothermal Heat Pump	Concrete ceilings
Käthe Dorsch Gasse	Residential	Geothermal Heat Pump, Solar thermal system, sewage, Photovoltaics	Concrete ceilings
Thoma	Residential, 2 flats	Geothermal Heat Pump and Freecooling, Photovoltaics	Wooden ceilings
Auenwerkstatt	Education	Solar thermal system, Ground-Collector Freecooling, Photovoltaics	Wooden ceilings and Concrete base plate
Fröschl Haus	Office	Groundwater: Heat Pump and Freecooling, Photovoltaics	Concrete ceilings
Campus V	Office	Biogas Boiler, Chiller	Concrete ceilings
Baumeisterhaus	Residential, 22 flats	Groundwater Heat Pump für Heating and Cooling, Photovoltaics	Exclusively for cooling: Concrete ceilings
HQ act4energy	Office	Air Heat Pump	Concrete ceilings

1.1 Energy and Comfort Monitoring

A standardised measurement concept was created for the monitoring, which is applied to all demonstration objects. The focus is placed on the energy supply and the parameters of the TABS applications.

All parameters are recorded and saved at quarter-hour intervals. The measurement data is analysed on a quarterly basis. The monitoring results are communicated to the demonstrator contacts after each evaluation cycle in the form of a clear analysis report.

Particular attention is paid to thermal comfort. A simplified, meaningful concept was developed for this purpose. On the one hand, the room air temperature and relative humidity are recorded at quarter-hourly intervals in representative rooms in all demonstrators. In addition, temperature profiles of the surrounding surfaces are measured quarterly in the representative rooms using a spot measuring device to determine the operative room temperature.

In addition to the quarterly spot measurements, 6 demonstrators were selected for in-depth monitoring of indoor comfort conditions. A detailed measurement of indoor comfort is carried out in winter and summer over 2 weeks in each case using the ISO 7730 method. Automated measuring equipment is used for this and placed in consultation with the users.

1.2 User and stakeholder survey

Three target groups were identified for the surveys:

1. The users
2. The practitioners and experts
3. The decision-makers

Question catalogues were drawn up for all 3 target groups and prepared in different forms. Target group 1 (users) is surveyed using an online questionnaire with a total of 28 questions. The aim of the survey is to record users' knowledge of the technology installed in their building and their personal experiences and satisfaction. Target groups 2 and 3 were surveyed in the form of interviews. The aim is to gather experience with TABS during the planning, construction and operation phases.

2. Monitoring and Analysis of Buildings with TABS

The Auenwerkstatt demonstration building is now used as an example for energy monitoring analyses. The Auenwerkstatt ist located in A-5151 Nussdorf am Haunsberg in the federal state of Salzburg. The owner is the federal state administration of Salzburg and it is used as an environmental education centre.

Figure 1. *Aerial view of the building Auenwerkstatt, source: RES Renewable energy Systems GmbH.*

The Auenwerkstatt is an energy self-sufficient building that is fully solar-heated and cooled via a ground collector. Power is supplied by a photovoltaic system with battery storage. A biodiesel CHP is used as a backup system for heat and electricity.

The heat and cold is stored and supplied to the utilisation zones via the following TABS:

- Wooden ceiling, solid wood “Holz100 aktiv Decke” of Thoma Holz GmbH [2], dispensing area approx. 298 m²
- Concrete base plate, dispensing area approx. 340 m², in-situ concrete, thickness 50 cm

Figure 2. *Interior view of multifunctional room*

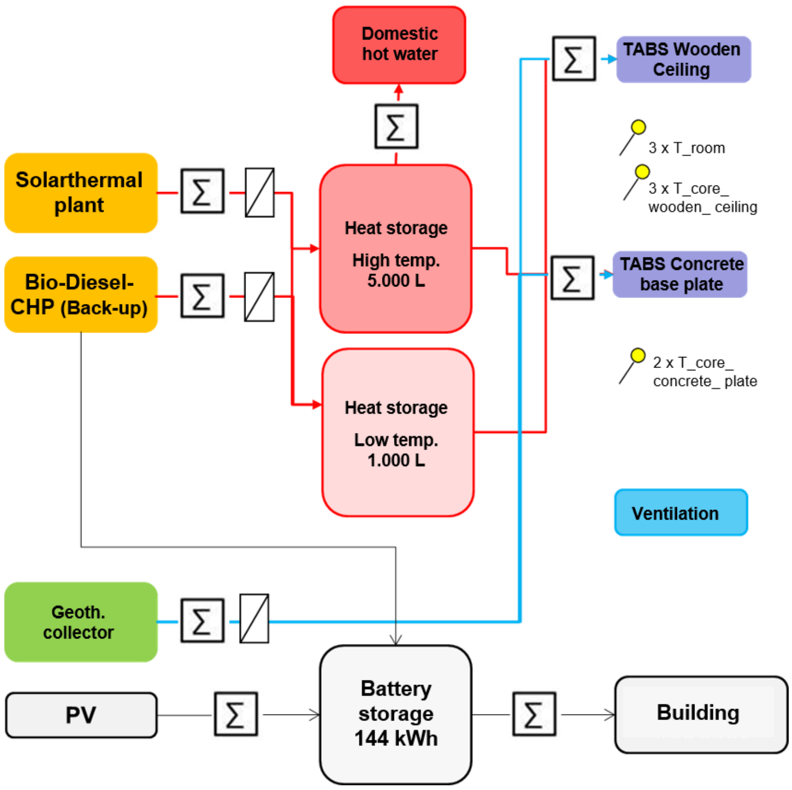

Figure 3. *Schematic illustration of the plant structure and measurement concept of the Auenwerkstatt.*

2.1 Energy Monitoring

The following figure shows the monthly balance of heat consumption for the period January to September 2023. As expected, space heating via TABS base plate and TABS wooden ceiling causes the highest heat consumption. The heat consumption for hot water preparation is a low proportion of 4.5%. The heating period ran until May 25, 2023. From this point on, the system technology was operated in cooling mode. On Oct. 1, 2023, the heating mode was activated.

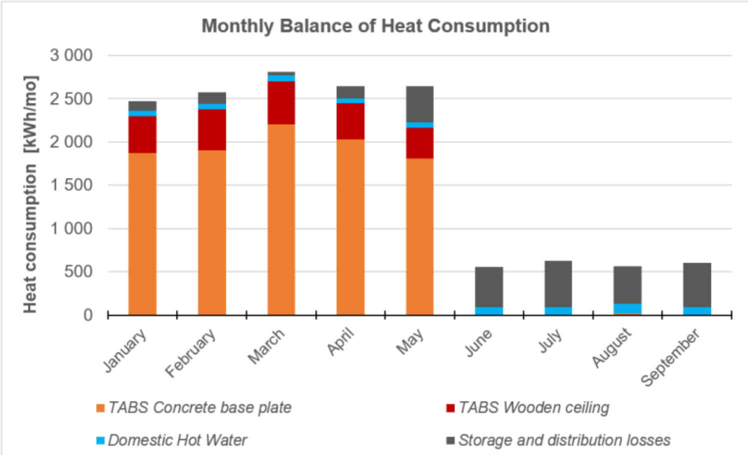

Figure 4. *Monthly balance of heat consumption, Auenwerkstatt, Jan. to Sept. 2023.*

The storage and distribution losses of the heating system amount to approx. 18%, which also benefits the room heat during the heating period. It is clear from the monthly balance sheet that storage and distribution losses have increased significantly from May 2023. The reason for this is the new setting for the high-temperature storage charging, which took place on May 25th. The set storage temperature has been increased from 62 to 85°C and a permanent flow has been set in the hot water supply network for the freshwater module. As a side effect the storage and distribution losses increase. During the heating period Jan. to May 2023, the heat dissipation splits up according to the following ratio:

- Wooden ceiling: 18%
- Concrete base plate: 82%

In the cooling period 75% of the total amount of cold was released via the TABS base plate and 25% via the TABS solid wooden ceiling.

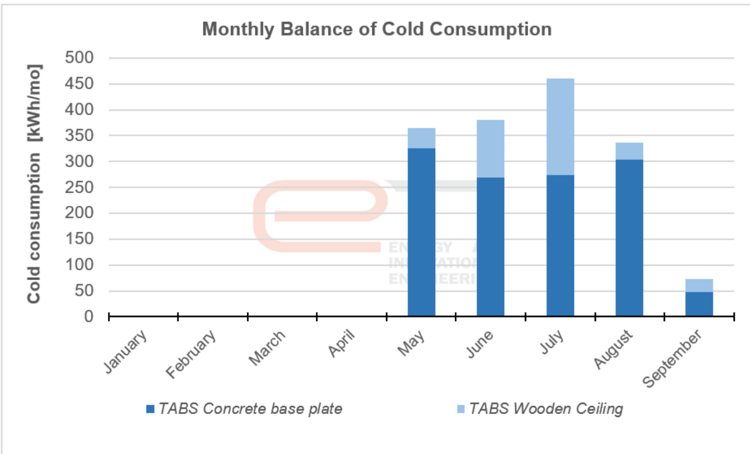

Figure 5. *Monthly balance of cold consumption, Auenwerkstatt, Jan. to Sept. 2023.*

The monitoring data shows that during the first 4 days of cooling operation in May (25-28 May), the cooling of the concrete slab was mainly active. The concrete component mass was cooled from 25°C to 22°C. This temperature was well maintained throughout the summer by the cooling operation, which ensured a pleasant indoor climate. It can be seen, that the large storage mass creates long-lasting, constant room comfort conditions and, for example, after the initial activation at the end of May, larger amounts of cooling are only required again after a few weeks (in the second half of June). The cooling via TABS wooden ceiling was mainly in use from the end of June to the end of July, otherwise hardly at all.

The following figures show the component temperatures of the TABS base plate and the TABS wooden ceiling for the cooling period June - August 2023. The diagrams confirm that cooling is mainly provided by the TABS base plate. Cooling via the wooden ceiling is only used to a small extent. The temperatures of the wooden ceiling are close to the room air temperature (0-1 K above room air temperature).

The temperature range of the floor slab during the cooling period is between 21-22°C.

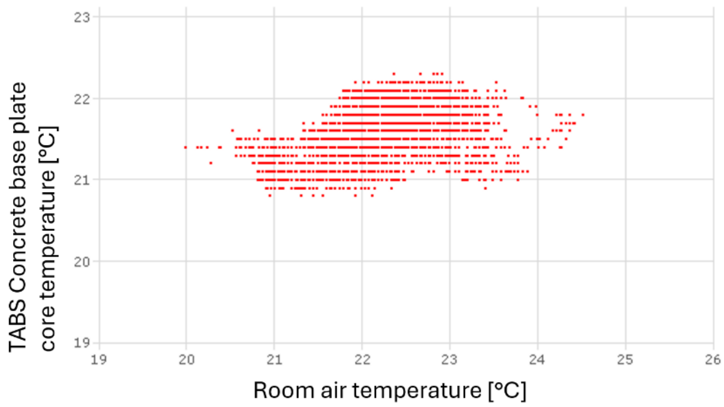

Figure 6. *TABS Concrete base plate core temperature, Multifunction-Room Auenwerkstatt, June. to Aug. 2023.*

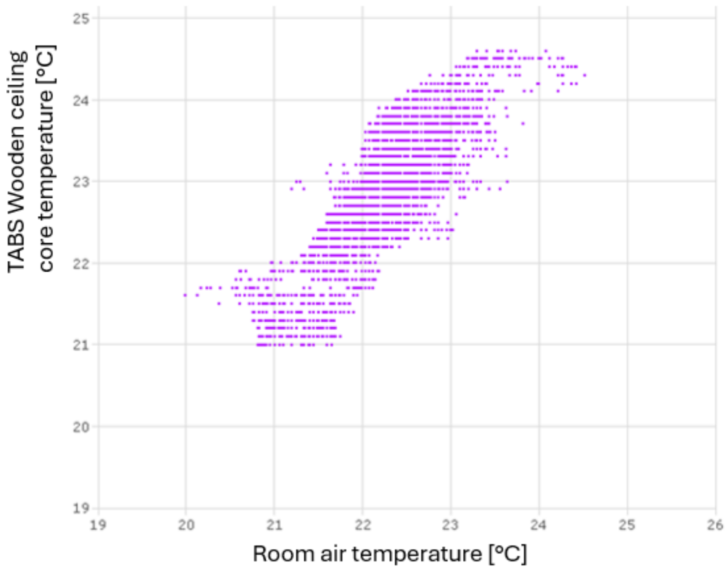

Figure 7. *TABS Wooden ceiling core temperature, Multifunction-Room Auenwerkstatt, June. to Aug. 2023.*

The following key performance indicators of the TABS in use were determined for heating and cooling operation:

Table 2. *KPIs of the TABS, Auenwerkstatt, Jan. to Sept. 2023.*

KPI	**TABS Wooden Ceiling**	**TABS Concrete Base Plate**
Activated area	ca. 298 m²	ca. 340 m²
Max. heating capacity	ca. 6,0 kW	ca. 25,0 kW
Max. specific heating capacity	20,7 W/m²	73,5 W/m²
Flow temperature for heating	27-30°C	27-30°C
Max. cooling capacity	ca. 2,2 kW	ca. 10,5 kW
Max. specific cooling capacity	ca. 7,4 W/m²	ca. 30,9 W/m²
Flow temperature for cooling	18,5-20,5°C	19,0-20,5°C

2.2 Comfort Monitoring

The comfort diagram shows that the room conditions during the winter months of January to April 2023 are largely still in the comfortable comfort range. The lowest room temperatures were recorded in the period from the end of January to the beginning of February (During this time, the building is only used very little). Apart from the cool periods in winter, a good indoor climate can be confirmed, as the relative indoor humidity in the reference rooms is very constant in the range of 35 - 45%.

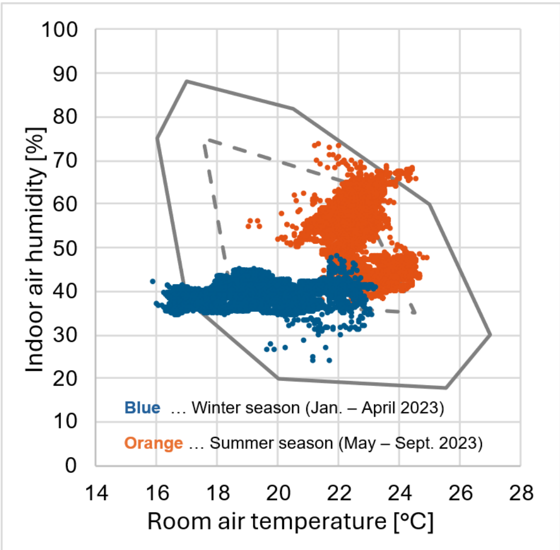

Figure 8. *Comfort diagram, Multifunction-Room Auenwerkstatt, Jan. to Sept. 2023.*

Very good indoor climate conditions were also recorded in the summer period - the indoor air conditions in the multifunctional room are largely within the comfort window.

The results of the operational temperature in the multifunctional room are shown below. These values were determined quarterly using the spot temperature measurement method. The operational temperatures determined in the multifunctional room also provide evidence of the good indoor climate.

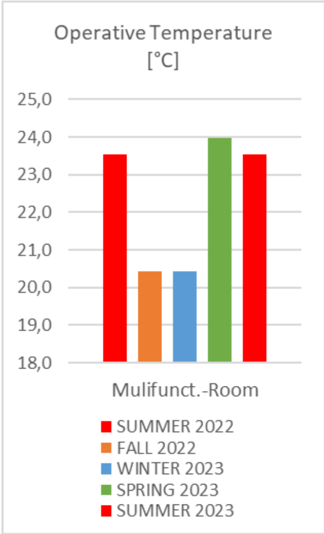

Figure 9. *Operational temperatures determined by spot measurement method, Multifunction-Room Auenwerkstatt.*

The comfort evaluation according to ÖNORM EN ISO 7730 considers following influencing variables:

- Air temperature
- Average radiation temperature of the room enclosure surfaces
- Air velocity
- Air humidity

For the comfort evaluation of the monitoring period Feb. 28 to March 07 2023 following boundary conditions were used:

- Clothing: Normal business clothing (0.154 m²K/W / clo=1.0)
- Activity: Sitting, light activity (70 W/m² / met_1.2)

The thermal sensation according to the PMV index (predicted mean vote) ranges between "slightly cool" (-1) and "optimal" (-0.5 to +0.5).

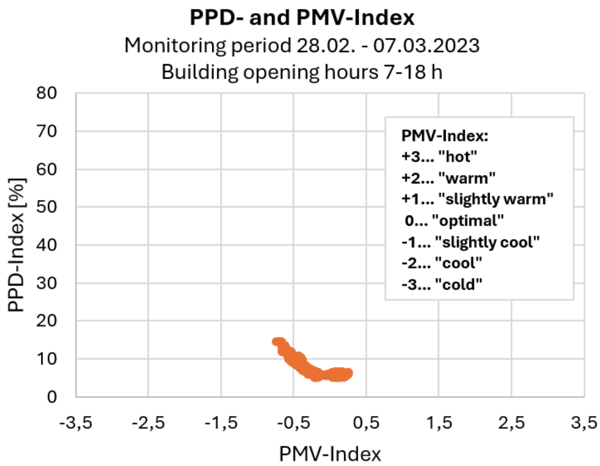

Figure 10. *PPD- and PVM-Index, Multifunction-Room, 28.02.-07.03.2023, Auenwerkstatt.*

The expected dissatisfaction rate (PPD index) is within the range of 5 - 14%. The PPD is higher during the morning hours, as the room temperature is still somewhat lower here.

The results show that the conditions in the multifunction room were largely pleasant and comfortable. The expected dissatisfaction rate "PPD index" averaged 8.7% during the seven days of measurement at the times of use from 7 a.m. to 6 p.m., which is an acceptable value.

2.3 Fundamental Findings from TABS Monitoring

Although the BTTAB project is still ongoing, the following 6 fundamental findings can already be summarised from the analyses of the buildings under investigation:

1. TABS examined are well-functioning systems. They fulfil their task as a heat and cold dissipation system and have a large storage capacity.
2. The users feel very comfortable in buildings with TABS. The technology creates a very pleasant indoor climate.
3. In office and residential buildings in particular, building users must be familiarised with the new technology. Initial training by competent personnel is recommended in any case in order to create a ready understanding of the TABS used.
4. TABS offer optimal conditions for the use of renewables, such as optimal temperature levels for heating and cooling, reduced peak loads compared to other available delivery systems in combination with a high storage capacity.
5. The great flexibility potential of TABS is utilised to a limited extent in the properties examined. In order to make the best possible use of the storage potential of TABS in combination with fluctuating renewable energy sources, more elaborated control strategies must be introduced in future.
6. For large-volume buildings, complex heating and cooling supply systems with different sources were implemented in some cases. The monitoring enabled the system operating behaviour to be analysed in detail over a period of one year. As a result, it was possible to draw up important optimisation recommendations for several buildings in order to increase the efficiency of the energy generation system.

2.4 Monitoring as an Instrument of Quality Assurance and Knowledge Generation

The project BTTAB illustrates that monitoring is highly relevant for innovative buildings with new technologies such as TABS. The monitoring of energy and comfort parameters proves to be an ideal instrument for monitoring the control operation of buildings, the individual technologies used and the interaction of complex plant structures. Monitoring makes it possible to assign the energy consumption to specific control settings of individual components or to specific user behaviour, to quickly locate faults and, if necessary, to counteract them with measures in the system operation or user behaviour. The effectiveness of implemented measures can also be quickly verified with the monitoring system at system level. The aim of energy and comfort monitoring is to continuously improve technical building operation and comfort conditions, to become more resource-efficient and to pass on the knowledge gained for future building projects.

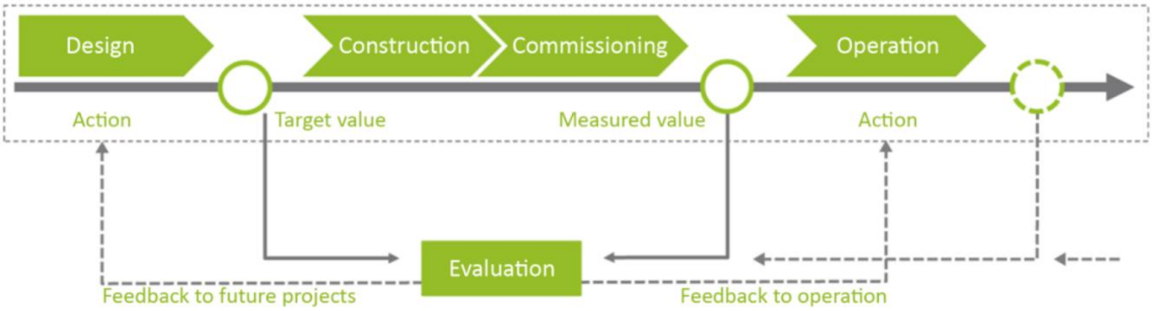

Figure 11. *Quality Control loop according to Technical Monitoring. [3]*

The Technical Monitoring (TMon) is recommended for quality assurance of the functionality of building services systems. TMon follows the concept of testing the fulfilment of requirements, thereby establishing a quality control loop for building performance. The service focuses on the precise definition of requirements as the basis for quality management and the application of well-defined testing procedures for those requirements. [3]

This monitoring method should be used to check and evaluate the performance of complex building technology systems. The transparent test method leads to success for the building, the owner, the planners and the users.

Data availability statement

The project results will be published as a final report at the end of the project, which can be accessed at the project website. Weblink see [1].

Competing interests

The authors declare that they have no competing interests.

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