hybrid GEOTABS

Controlling the power of the ground by integration

hybridGEOTABS project summary

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GEOTABS hybrid brings together a transdisciplinary team of SMEs, large industry and research institutes, experienced in research and application of design and control systems in the combined building and energy world.

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Summary of the hybridGEOTABS Project

Concept

The European Union has set a path towards a decarbonised society in 2050. The European Green Deal aims to reduce the CO_2-emissions by at least 55% by 2030. Heating and cooling of buildings constitutes a significant part of the energy use in Europe, and is therefore an important sector in the transition to this low-carbon society. hybridGEOTABS is an HVAC-concept that provides comfort in buildings in a clean and sustainable way.

The core of the concept is GEOTABS: a combination of a geothermal system (GEO) and thermally activated building systems (TABS). TABS is a type of radiant heating and cooling emission system that is well-known for providing high thermal comfort. The heating/cooling pipes are embedded in the mass of the building elements (e.g. concrete floor slabs), therefore activating them as thermal storage. By turning entire floor or ceiling surfaces into heating and cooling systems, TABS can provide very low-temperature heating (as low as 22 - 28°C) and high-temperature cooling (as high as 15 - 22°C). These temperatures are close to the temperatures available in the shallow layers of the underground, which allows to operate geothermal (GEO) heat pumps at a very high efficiency. Moreover, in buildings with moderate cooling demands (e.g. in central and northern Europe), the underground temperatures can be directly transferred to the TABS via a heat exchanger, providing passive cooling at negligible energy cost. The geothermal source acts as a seasonal storage, from which heat is extracted in the heating season and injected again in the cooling season. This seasonal energy storage, combined with the short-term thermal energy storage in the TABS, enables an enhanced use of renewable energy. GEOTABS is the comfortable and sustainable core of the hybridGEOTABS system.

GEOTABS becomes a hybrid system by combining it with secondary heating and cooling emission and/or production systems. Because of their high thermal inertia, TABS require flexible complementary heating/cooling emission systems (e.g. radiators, or integration with the building air-handling system) to swiftly react to variations in heating or cooling setpoint, ensuring thermal comfort and efficient operation at all times. On the production side, investments can become more competitive when providing a cheaper secondary supply system to cover the peak demands and other heating loads of the building (e.g. hot water generation), or even more environmentally friendly by adding secondary renewable systems. This flexibility on the secondary side is inherent to hybridGEOTABS and this flexibility allows to develop hybridGEOTABS buildings for the different climates in EU, for different building typologies, for a broad spectrum of design possibilities in the architectural language (e.g. buildings with a lot of glazing or high internal heat gains) and for the various objectives a building energy concept designer may have (e.g. 100% RES, all-electric building, NZEB etc.). The hybrid system increases the (energy, environmental, IEQ, financial) performance and feasibility of the overall HVAC-system, thus increasing its application field to a much wider range of building designs.

To also realise the potential of this hybrid concept in reality, it does require an adequate system integration and smart control based on exchange of information between the building zones, the various levels of the systems and the energy grids. Each moment, the system has to be able to decide how much heating or cooling to provide to the TABS or secondary emission system in order to optimise comfort, to decide which energy supply system is the most energy- or cost- efficient to use, and how much energy to store in the TABS and geothermal source. In the hybridGEOTABS concept, the vital role of controlling the system is taken up by a Model Predictive Controller (MPC), which optimises the operational efficiency of the system in terms of energy, environmental and/or cost performance while safeguarding the indoor environmental quality constraints and even watching over the interaction with the smart electricity grid or availability of renewable energy sources.

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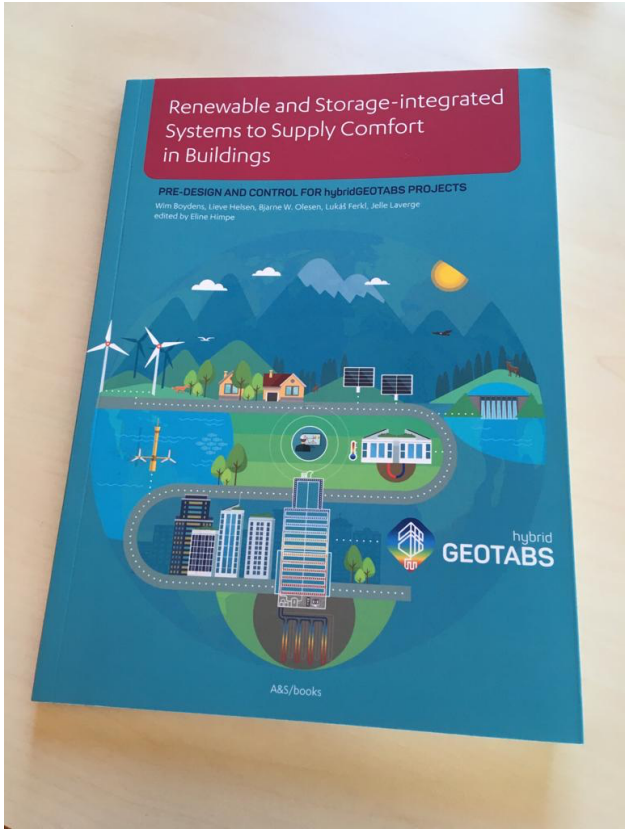
Objectives

To allow for a wider implementation of this environmentally friendly and smart-grid-ready technology in the EU market, this project tackles the major bottlenecks of the hybridGEOTABS concept. A first challenge is how to design such a hybridGEOTABS building, with its hybrid systems, integrated storage and smart control? In order to give a fair chance for the hybridGEOTABS concept to be considered and selected by the energy concept designer, a straightforward and easy-to-use design method is developed, that integrates the key properties of the building, the HVAC-systems and the control, in order to come to an optimised design and performance of the hybridGEOTABS building. A second challenge is the development of a suitable control system with model predictive control, that improves the overall energy-efficiency of the system. A semi-automated MPC toolchain is developed and MPCs are demonstrated and tested in four demonstration buildings. This leads to the third objective, that is to demonstrate the hybridGEOTABS concept in building energy simulations and real-life buildings, and to assess its performance in terms of energy use, environment, indoor environmental quality, health, productivity and costs. The fourth objective is the establishment of a knowledge centre for hybridGEOTABS, called enerCORE, that will promote the concept and establishes the best practices, while guiding further development of the concept. The solution will support the industry and SME's to expand their activities and strengthen competitiveness, resulting in an increased market share of energy efficient buildings and HVAC solutions. European citizens will benefit from increased IEQ in buildings, the positive impact on growth and employment, and access to enhanced goods and services of high societal value.

To address these challenges the hybridGEOTABS project brought together a transdisciplinary team of SME's, large industry and research institutes, experienced in research and application of design and control systems in the building and energy world.

Outcomes



The hybridGEOTABS book "Renewable and Storage-integrated Systems to Supply Comfort in Buildings" (www.hybridgeotabs.eu/publications/guidebooks) explains to the broader public the hybridGEOTABS concept, history and state-of-the-art, the control and design challenges and solutions developed in this project, the main assets and exemplary hybridGEOTABS buildings in Europe.

The hybridGEOTABS design webtool, available on www.hybridgeotabs.eu, allows the energy concept designer, HVAC-designer and architect to assess the feasibility of hybridGEOTABS for their building project from the earliest stages of the design onwards. Starting from basic information about the building project as input, the sizing and performance of hybridGEOTABS are provided, together with quantifications of the energy behaviour, energy and environmental performance and life-cycle cost of the hybridGEOTABS and alternative HVAC-concepts. This design tool links to a database with almost 150,000 pre-simulated and pre-engineered buildings, based on a newly developed design methodology.

The buildings include school, office, elderly home and multi-family typologies in the three major EU climates, represented by Madrid, Brussels and Warsaw. It is found that when using traditional (steady-state) HVAC-design methods (instead of the design tool), the sizing of hybridGEOTABS components is significantly overestimated, leading to an increased investment costs. The design tool is accompanied by a manual and a set of design decision trees providing a first guidance on the hybridGEOTABS applicability. Furthermore, modular schematics of the concept are available, as well as a set of hydraulic schemes for various system configurations, constituting a basis for accelerating the start of the detailed system design. One of our two training curricula 'How to design and operate hybridGEOTABS' provides training modules on the hybridGEOTABS concept and MPC, the design tool, and the detailed design of the key system components. For the detailed design of the geothermal borefield, which is the most expensive part of the hybridGEOTABS system, the project demonstrates investment cost reductions of 7-11% and borefield length reductions of 10% by optimising the design using an enhanced geothermal response test. As an alternative to TABS in context of building renovations or light-weight buildings, ceiling panels with integrated phase change materials (PCM) were developed and tested. Finally, generic specifications for tendering of the hybridGEOTABS system components are available.

The semi-automated toolchain for developing the (white-box) model predictive controller allows using MPC for both high- and low- level control, increasing the energy use, cost savings and thermal discomfort reductions. The MPC solution is able to connect to any building management system that supports open communication protocols (e.g. BACnet). It uses the measurement data and it sends set-points to the controllers or direct control signals to the devices through the building management system. By this, the main challenges of the MPC framework are tackled. The MPC-toolchain has been implemented in three real-life demonstration buildings. Secondly, improvements of grey-box MPC were investigated and implemented in the fourth demonstration building. Adaptability of the MPC during operation was investigated, leading to verified adaptive algorithms to take into account real-life occupancy estimation and window-opening detection. Different MPC formulations were tested in a real-life small-scale test building, in order to obtain more robust MPC formulations (with less oscillatory behaviour) that lead to energy savings up to 10% as compared to the conventional grey-box MPC formulation. The MPC controllers are Smart Grid ready, e.g. variable electricity prices can be taken into account in the controller, to optimise the building control towards grid flexibility and allowing to exploit the demand-shifting that is inherently possible with the GEOTABS, thanks to its high thermal inertia.

hybridGEOTABS demonstration buildings in Europe: Solarwind office building (Windhof, Luxembourg); Infrax/Fluvius office building (Dilbeek, Belgium); Ter Potterie elderly home (Bruges, Belgium), Haus M (Zürich, Switzerland) and Libeznice school (Czech Republic)

During the project, MPC was implemented in four hybridGEOTABS demonstration buildings: an elementary school in Libeznice (CZ), an office building 'Infrax/Fluvius' in Brussels (BE), an elderly care home 'Ter Potterie' in Bruges (BE) and an office building 'Solarwind' in Windhof (LU). Moreover, a building energy simulations of these buildings and the Haus M multi-family building in Zürich (CH), complete the testbed. The buildings are introduced on the project website and video (https://youtu.be/Kf5vOozx5dU). Based on the building energy simulations, it primary energy savings between 6% and 48% were identified by hybridGEOTABS buildings (as compared to traditional HVAC-technologies; and assuming a non-renewable secondary system is used in the hybridGEOTABS concept). The improved system operation thanks to the MPC causes additional HVAC energy use reductions up to 37% in the simulations and up to 24% in the real-life measurements. The IEQ, health and productivity in the demonstration buildings have been monitored over the past years, using in situ measurements and questionnaires. The overall conclusion is that the IEQ in all the demonstration buildings is good, also when MPC is installed, and the indoor air quality was rated as high. The increased system energy efficiency also leads to significant CO_2-emission reductions. Furthermore, it is found that hybridGEOTABS buildings profit much more than traditional HVAC-systems from the future low-carbon electricity mix in the EU by 2030 and 2050. This makes them real players in the low-carbon society: with HVAC CO_2-emissions below 2 $kgCO_2/m^2$/year, on top of their inherent heat storage capabilities, they leave traditional HVAC-solutions far behind. The life cycle costs of hybridGEOTABS scenarios with and without MPC are similar (differences < 1%), and about 0.5% to 4.6% higher than traditional non-renewable HVAC-concepts.

Impact

The feasibility of hybridGEOTABS and its potential environmental impact on the newly constructed building stock in the EU is assessed using the CO_2-emission reductions as the main indicator. Looking at the variety of building designs in the EU, it is found that in all climate zones for half of the buildings, 50% to 100% of the heating and cooling demands can be covered by GEOTABS, and the remainder by the secondary system. The CO_2-emission reductions are estimated by comparing the performance of hybridGEOTABS with MPC to the traditional non-renewable HVAC-solution, based on simulations of the relevant section of the EU building stock. The building stock and four typologies studied account for 40% of the newly-constructed multi-family residential building stock surface area, and 50% of the newly constructed non-residential building stock surface area in the EU (representing the stock of office, school and elderly care home buildings). The results of this study show that GEOTABS reduces the CO_2-emissions related to heating and cooling of new buildings in the EU by about 40%. If in the next decade, all new buildings of the studied typologies in the EU would implement hybridGEOTABS, this would save about 26.5 $MtCO_2$ over the next ten years. Note that these savings are attributed only to the GEOTABS part of the building. By optimising the building design for the use of GEOTABS and/or by combining the GEOTABS core with renewable secondary systems (e.g. solar boiler, air-source heat pump), further CO_2-emission reductions can easily be achieved. Moreover, the combination of hybridGEOTABS with photovoltaic is found a highly advantageous solution in all EU climate zones, reducing the global financial cost up to 2% as compared to the situation without PV. From the overall financial point of view, it is estimated that an increase of about 7% in the NPV can reduce the environmental impact of buildings with about 95% (in colder climates), 70% (in moderate climates) and 20% (in the Mediterranean).

These results indicate the large potential of hybridGEOTABS in the EU. The newly developed design strategies, component optimisations and model predictive controls, demonstrated in real-life hybridGEOTABS buildings and supported by the enerCORE knowledge centre for hybridGEOTABS… they all have the potential to contribute to a broader implementation of the hybridGEOTABS concept that can play an important role in reaching the European targets on increasing energy-efficiency and RES, and reducing GHG-emission, thereby safeguarding quality of life of building users and architects' freedom to create buildings that make a real difference… where architectural design qualities and sustainability meet!