

# Key Modules and Optimization Approach for hybrid GEOTABS Buildings:

## Background and state-of-the-art



**HÉCTOR CANO ESTEBAN**

MSc, Project Manager in "R&D and Projects Department", Geothermal Energy S.L, Spain  
hector.cano@geoter.es



**QIAN WANG**

PhD, Research and Innovation Specialist, Uponor AB, Västerås, Sweden/ Division of Fluid and Climate Technology, KTH Royal Institute of Technology, Stockholm, Sweden  
qian.wang@uponor.com



**JAN HOOGMARTENS**

Ing. Project Engineer, Viessmann Belgium bvba  
hooj@viessmann.com



**ONGUN BERK KAZANCI**

PhD. Assistant Professor, International Centre for Indoor Environment and Energy Department of Civil Engineering, Technical University of Denmark  
onka@byg.dtu.dk

hybrid GEOTABS is an EU H2020 funded research project focusing on the design, development and optimization of the innovative concept combining thermally active building systems (TABS), geothermal, heat pump and model predictive control (MPC). As the first article of a serial of project disseminations, this paper introduces the working principle of hybrid GEOTABS, as well as their main components/modules. The optimization approach of key modules in common practice is also discussed. This article aims at providing a basic knowledge of the concept as a preparation for the up-coming optimization development and integration of the involved key modules.

**Keywords:** hybridGEOTABS; geothermal heat pump; TABS; radiant heating and cooling

### Introduction of hybrid MPC GEOTABS and its key modules

GEOTABS buildings combine an energy efficient heating and cooling system (Thermally Active Building Systems, TABS) with renewable resource (ground, GEO) to heat

and cool buildings in a sustainable way. The performance of GEOTABS buildings has been studied thoroughly in an earlier EU project, GEOTABS - Towards Optimal Design and Control of Geothermal Heat Pumps Combined with Thermally Activated Building Systems in Offices [1].

A more recent EU project (HORIZON 2020-10 project EE-04-2016, Model Predictive Control and Innovative System Integration of GEOTABS in Hybrid Low Grade Thermal Energy Systems - hybrid GEOTABS [2]) is taking the analysis that were carried out within the GEOTABS project further. A previous publication has already summarized the project scope, tasks, and goals [3].

Within the scope of this project, hybrid GEOTABS buildings are studied in detail in terms of optimal system design and dimensioning methodology, control, and in other terms, including but not limited to, energy performance, indoor environmental quality (IEQ), costs, environmental impacts, and so forth. Model Predictive Control (MPC) algorithms are being developed and the developed algorithms will be implemented in chosen demonstration buildings. The three demonstration buildings are an office building in Luxembourg, an elderly care home in Belgium, and an elementary school in Czech Republic. All these buildings are equipped with hybrid GEOTABS systems. In addition to these three demonstration buildings, there are also two case study buildings: a residential building and another office building.

In addition to the GEOTABS, the hybridGEOTABS buildings can have “hybrid” heat emission/removal systems and also “hybrid” energy sources. This enables having other room conditioning systems in addition to

TABS, and gives the possibility of benefiting from other heat sources and sinks than the ground. MPC ensures the optimal operation of the systems in such buildings.

Previous studies have identified the system concept, individual modules, and the interfaces between system components of hybrid GEOTABS buildings [4], the MPC concept with a focus on hybridgeotabs buildings [5], together with the detailed measurements of thermal indoor environment in the chosen demonstration buildings [6].

As the first article of this serial, this study focuses on introducing the TABS, heat pumps (ground source) and the ground heat exchangers, and their optimization process for the application in hybridGEOTABS buildings.

## Hydronic radiant heating and cooling systems

### General description

A hydronic (water-based) radiant heating and cooling system refers to a system where water is the heat carrier and more than half of the heat exchange with the conditioned space is by radiation (heat emission to or removal from the space is by a combination of radiation and convection). There are three types of radiant heating and cooling systems [7]:



## hybridGEOTABS

– *Model Predictive Control and Innovative System Integration of GEOTABS in Hybrid Low Grade Thermal Energy Systems*

*hybridGEOTABS is a four-year project started in 2016 by an active team of SMEs, manufacturers and research institutes. The project, led by the University of Gent, is a Research and Innovation Action funded under the EU's Horizon 2020 programme.*

*The goal of hybridGEOTABS is to optimise the predesign and operation of a hybrid combination of geo-thermal heat-pumps (GEO-HP) and thermally activate building systems (TABS), alongside secondary heating & cooling systems, including automated Model Predictive Control (MPC) solutions.*

*To know more about the project visit [www.hybridgeotabs.eu](http://www.hybridgeotabs.eu) and contact [hybridgeotabs@ugent.be](mailto:hybridgeotabs@ugent.be)*



*hybridGEOTABS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723649.*

- Radiant heating and cooling panels;
- Pipes isolated from the main building structure (radiant surface systems);
- Pipes embedded in the main building structure (Thermally Active Building Systems, TABS)

Hydronic radiant heating and cooling systems are low temperature heating and high temperature cooling systems. Therefore, the heat carrier (water) circulating in the pipes has low temperatures in heating and high temperatures in cooling operation. In some TABS constructions (hollow core concrete decks), also air has been used as a heat carrier, and electricity can also be used in some radiant heating applications [8].

Floor, wall and ceilings can be used as surfaces that provide heating or cooling to the space. Hydronic radiant surface systems can address only sensible heating and cooling loads. Therefore, they require a ventilation system to address the latent loads and to provide the ventilation rates required for indoor air quality concerns [7]

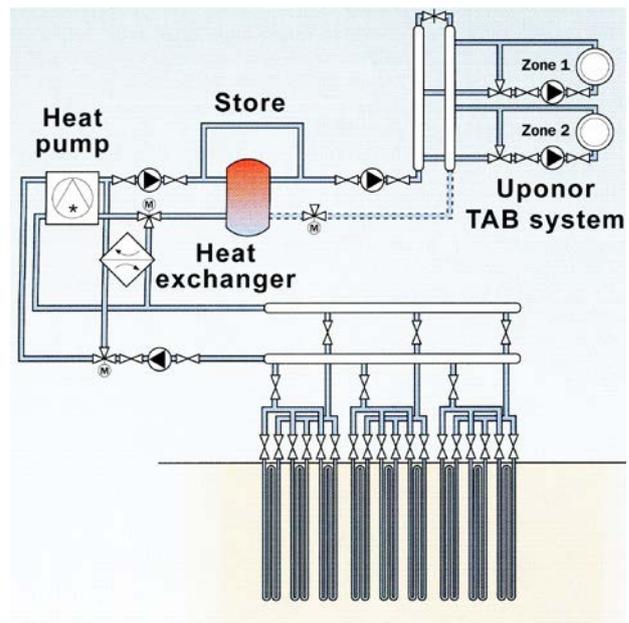
Radiant heating and cooling systems enable lower airflow rates than all-air systems, in which the entire heating and cooling loads are addressed by the ventilation system [9].

### **TABS and its optimization approach**

TABS has emerged as an innovative solution to improve building energy performance and indoor climate. As introduced, TABS combine cooling and heating system in the structural concrete slabs/walls of a multi-storey building, which can operate hydraulic temperature close to ambient temperature from 22–29°C for heating and 16–22°C for cooling [10]

TABS are primary used for sensible cooling and secondarily for base heating. The whole system works with radiant heating and cooling, which is not any air-conditioning or radiators, and does not commonly substitute any ventilation system. Furthermore, TABS stores heat via building structures themselves and can commonly provide upgraded global thermal comfort than conventional convective heating/cooling methods [10]

Due to the reduced draught, noise levels and improved mean radiant temperature through less fluctuated surface temperature, local thermal comfort is commonly high in TABS buildings. All the above advantages have promoted TABS as a competitive heating/cooling emission system in the current EU building markets. TABS-served low-temperature heating (LTH) and high-



**Figure 1.** GEOTABS system. [7]

temperature cooling (HTC) provide wide opportunities for the integrations and applications of renewable energy, such as geothermal energy or ground-source heat pumps (hereafter refer as GEOTABS) [11]

**Figure 1** shows a typical GEOTABS system that serves heating and cooling in a building with multi-zones.

TABS as a mature product has been available on the market. The optimization approach of TABS mostly lies in the configuration design of TABS to maximize its outputs based on various construction conditions of the slab/ceiling. In principle, ceiling configurations without insulation or air gap are ideal for maximizing the output of TABS. Five typical optimal methods, used based on ceiling design, have been suggested in **Table 1** [7] [10]

### **Heat pump and secondary system module and its optimization**

The heat pumps are a major component in the hybridGEOTABS concept. The geothermal heat pump serves the upgrade from low temperature geothermal energy to high(er) temperature TABS heating energy. Traditionally geothermal heat pumps are tested following existing standard (EN 14511, EN 14825) for low temperature (35°C) and medium temperature application (55°C). As TABS uses lower supply temperatures than 35°C, (typically 22–29°C, as introduced), it is more interesting to investigate the performance at even lower supply temperatures.

This will be done by a lab test where three parameters will be changed:

- lowering supply temperature from 35°C to 25°C
- varying the temperature difference at evaporator side
- varying the temperature difference at condenser side.

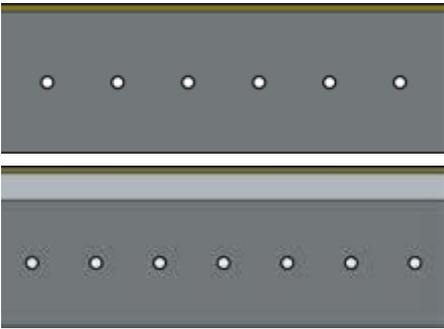
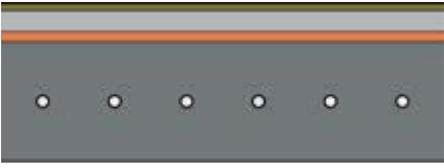
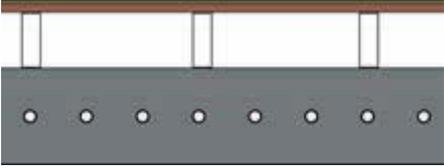
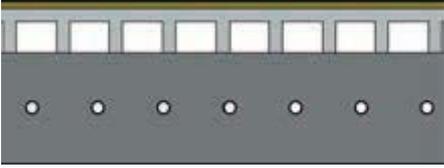
Last two variables will give information concerning the trade-off between heat pump efficiency (COP-value) and circulation pump energy consumption. Furthermore, the varying primary temperature difference will influence the geothermal bore field performance.

Not only is the performance of the heat pump refrigerant cycle important to improve, but also other parameters of geothermal heat pump system do have an important role in the general system performance (e.g. next generation refrigerants, next advanced circulation pumps, the control of the heat pump). Those

parameters will be evaluated together with important market players.

In this hybridGEOTABS project, the geothermal heat pumps deliver the base load in heating and cooling mode. Additional heating and cooling energy are generated by a secondary heating/cooling system. The hydraulic interaction between the base load of the heat pump and the peak load of the bivalent system is very important and will have a big impact on system performance. For all demo buildings in the project, an energy concept is available. In all cases low temperature TABS heating and high temperature top heating were separated from each other. Often fossil boilers were used as the peak load system. Those boilers are less sensible for varying temperatures, temperature differences. Via the hydraulic design, the risk of overruling the heat pump working should be avoided.

Table 1. TABS based on basic ceiling configurations.

Slab type	Structure	Optimal application of TABS
Concrete slab with or without bonded screed		Concrete slabs with only a thin floor covering or bonded screed deliver heating and cooling into the room
Concrete slab with sound insulation		Sound insulation reduces output via the floor. This design option is acceptable in applications where mainly the effect of cool ceilings is utilized.
Concrete slab with raised floor		For a raised floor, the same considerations apply as for a floor with sound insulation. This type of ceiling construction is popular because power supply and cables can be installed in the void.
Concrete slab with hollow floor		Another variant that is frequently used in office buildings is the hollow floor construction. In terms of performance, it behaves similarly to the false floor. However, because screed (instead of floor panels) is used, inspection openings must be used for the underfloor installations.

Next to hydraulic interaction between base load and peak load, the control between both generators is important. Based on different optimization criteria (e.g., functional cost, energy savings, CO<sub>2</sub>-reduction, bore field utilization) both generators will be controlled in a different way.

Available heat pumps in the market have basic input possibilities to communicate with existing Rule Based Controllers (RBC, going from potential free liberation/blocking contact towards 0-10V temperature control). Future Model Predictive Controllers (MPC) may need other data points to write to the future heat pump controller. Additionally, more reading signals can be interesting for future MPC controllers. The wish list of possible reading and writing parameters will get a reality check for current available heat pump and back-up system controllers. Possibilities to develop/extend current controllers will be investigated throughout the project.

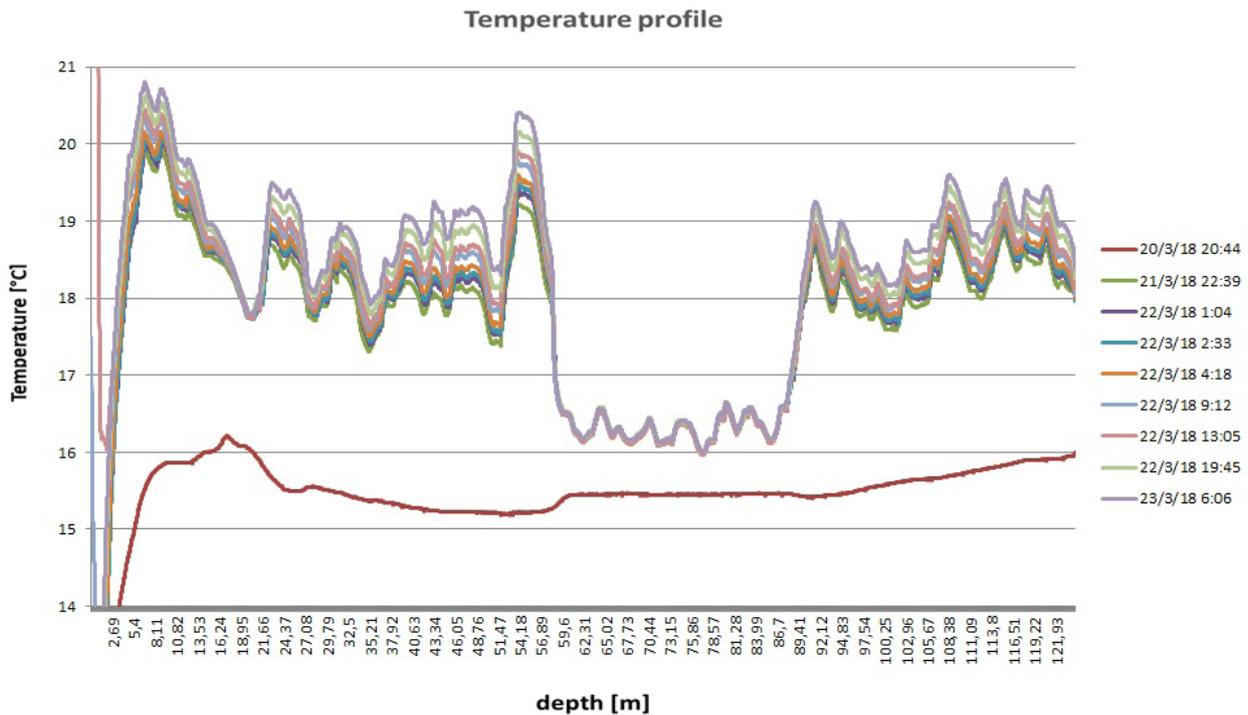
### Geothermal and renewable supply module optimization

One of the key issues that needs to be optimized for ground heat exchangers (GHEX) is the optimization of borehole field. In order to optimally size the geothermal borehole field, the use of a GRT (Geothermal Response Test) is the most prevalent practice. It is an on-site

test to determine the thermodynamic parameters of the subsoil. Its execution allows to know the effective thermal conductivity, which describes the heat transfer through conductivity in the subsoil, and the thermal resistance of the probe. It indicates what should be the thermal leap between the collector circuit and the subsoil for the dissipation of the power applied to the circuit.

In hybridGEOTABS project, improvements in this process have been achieved by executing more developed, upgraded and detailed GRTs than common practice. In a traditional GRT, only the flow and return temperatures at the top of the borehole are measured, while an Enhanced Geothermal Response Test (EGRT) enable us to obtain a temperature profile at all the levels of the borehole, measuring accurately how the temperature changes with depth as a function of the flow and the thermal stress of the borehole. It allows engineers to understand the optimal areas of the sub-soil are and even, to evaluate the influence of the different materials or groundwater in the case that these exists.

During realization of the EGRT (See **Figure 2**), the temperature of the ground has been obtained, depending on the depth during a heating controlled process. The red curve validates the typical theoretical depth-temperature unaltered profile of the earth. The



**Figure 2.** Temperature profile during EGRT execution.

rest colours represent temperature profile along the borehole length, which have been represented as a function of time to verify the temperature changes while a constant heat is injected. With all the information, conductivity along the borehole can be obtained and the optimal depth of the boreholes can be calculated taking into account the thermal loads of the building which we want to provide heating/cooling and DHW. Thermal conductivity differences are explained by the different hydrogeological conditions.

Subsequently, three different simulations were carried out with EED (Earth Energy Designer) software to show the importance of knowing the conductivity along the borehole. In all of them VDI 4640 Guideline has been considered [12] – [16]:

1. Simulations performed by engineering, when the conductivity is estimated based on geological and hydrogeological bibliographic studies as well as on the experience.
2. Simulations performed after performing GRT, when the average conductivity is known.
3. Simulations performed after performing an EGRT, when the conductivity is known throughout the depth.

The required heat exchanger is longer when conductivity has been obtained from engineering than when has been determined by the GRT, due to the oversizing that used to be done for the estimation of conductivity. Similarly, the required exchanger length is higher when conductivity has been obtained from GRT than when has been determined by the EGRT because it is possible to optimize the length of the boreholes. After six different EGRTs executed we can affirm that pre-engineering sizing has a reduction of 4–10% of investment performing a GRT and a reduction of 14–16% performing an EGRT. That means, an EGRT has meant a 7% investment reduction compared to the GRT.

Through an EGRT, areas of high conductivity have been found along the depth, and together with the study through EED software has allowed the optimization of the global geothermal system. Performing an EGRT is possible to analyse the complete information about the subsoil and decide the best solution considering all the project conditions, always optimizing the number of meters to drill. EGRT obtains savings in investment costs without penalizing the optimum functioning of the HVAC installation.

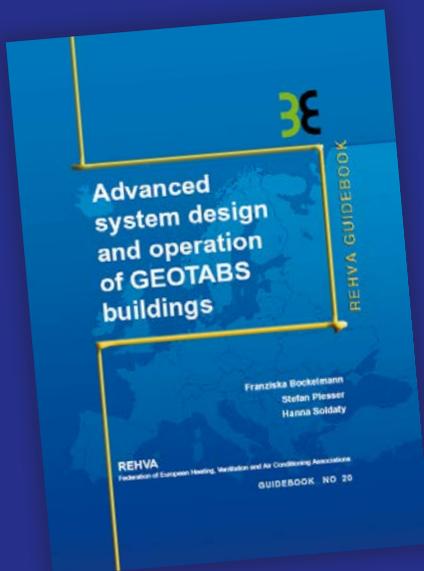
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No.20

### Advanced system design and operation of GEOTABS buildings

This REHVA Task Force, in cooperation with CEN, prepared technical definitions and energy calculation principles for nearly zero energy buildings required in the implementation of the Energy performance of buildings directive recast. This 2013 revision replaces 2011 version. These technical definitions and specifications were prepared in the level of detail to be suitable for the implementation in national building codes. The intention of the Task Force is to help the experts in the Member States to define the nearly zero energy buildings in a uniform way in national regulation.

**Orders:** [info@rehva.eu](mailto:info@rehva.eu)



## Conclusion

As a renewable source, geothermal is an efficient and abundant energy globally, in this content, it is more important to use this resource efficiently in corrected designed systems. The combination of TABS, heat pumps and GHEX shows to be an efficient solution that has potentials to maximize the advantages of each component. Different approaches of how each module are optimized as common practices have been introduced in this article. However, the challenges lie in the further integration and interactions of the above modules/components by means of, e.g., MPC control system. These aspects will be continuing introduced in the following up articles in the serial. ■

## Acknowledgments

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## References

- [1] [www.geotabs.eu](http://www.geotabs.eu), 6 March 2018. [Online].
- [2] [www.hybridgeotabs.eu](http://www.hybridgeotabs.eu), 6 March 2018. [Online].
- [3] Jorissen, Filip, et al. "hybridGEOTABS project-MPC for controlling the power of the ground by integration." *The REHVA European HVAC Journal* 55.3 (2018): 58-64.
- [4] Khovalyg, D., Kazanci, O. B., Parnis, G., Cigler, J., & Olesen, B. W. (2019). Hybrid GEOTABS: System Concept, Individual Modules, and Interfaces. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2019 ASHRAE Winter Conference.
- [5] Cupeiro Figueroa, Iago, Jiří Cigler, and Lieve Helsen. "Model Predictive Control Formulation: A Review with Focus on Hybrid GEOTABS Buildings." *Proceedings of REHVA Annual Meeting Conference Low Carbon Technologies in HVAC*. 2018.
- [6] Kazanci, O. B., Khovalyg, D., & Olesen, B. W. (2018). Development of a field measurement methodology for studying the thermal indoor environment in hybrid GEOTABS buildings. *Proceedings of the REHVA Annual Meeting Conference - Low Carbon Technologies in HVAC*. Brussels: REHVA & ATIC.
- [7] REHVA 007: J. Babiak, B. W. Olesen and D. Petráš, *Low temperature heating and high temperature cooling*, Brussels: REHVA - Federation of European Heating, Ventilation and Air Conditioning Associations, 2009.
- [8] O. B. Kazanci, "Low temperature heating and high temperature cooling in buildings, PhD Thesis," Technical University of Denmark, Kgs. Lyngby, 2016.
- [9] B. W. Olesen, "Using Building Mass To Heat and Cool," *ASHRAE Journal*, vol. 54, no. 2, pp. 44-52, 2012.
- [10] Uponor. *Uponor Contact compendium - Thermally active building systems*. 2014.
- [11] Wang, Qian, and Suleyman Dag. "Business Model Analysis of Geo-TABS Buildings with Predictive Control Systems." *Cold Climate HVAC Conference*. Springer, Cham, 2018.
- [12] *Manual de geotermia*. Instituto Geológico y Minero de España (Ministerio de Ciencia e Innovación) e Instituto para la Diversificación y Ahorro de la Energía (IDAE).
- [13] *Cambio climático 2014. Impactos, adaptación y vulnerabilidad (2014)*. Contribución del grupo de trabajo II al Quinto Informe de Evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático. Recuperado de: IPCC
- [14] *Evaluación Preliminar de los Impactos en España por Efecto del Cambio Climático (2005)*.
- [15] International Ground Source Heat Pump Association (IGSHPA). *Manual "Design and Installation Guide"*.
- [16] *Convenio de colaboración entre el Ministerio de Medio Ambiente y la Universidad de Castilla-La Mancha en materia de investigación sobre una "Evaluación preliminar general sobre los impactos en España por efecto del cambio climático"*. Recuperado de: Proyecto ECCE.