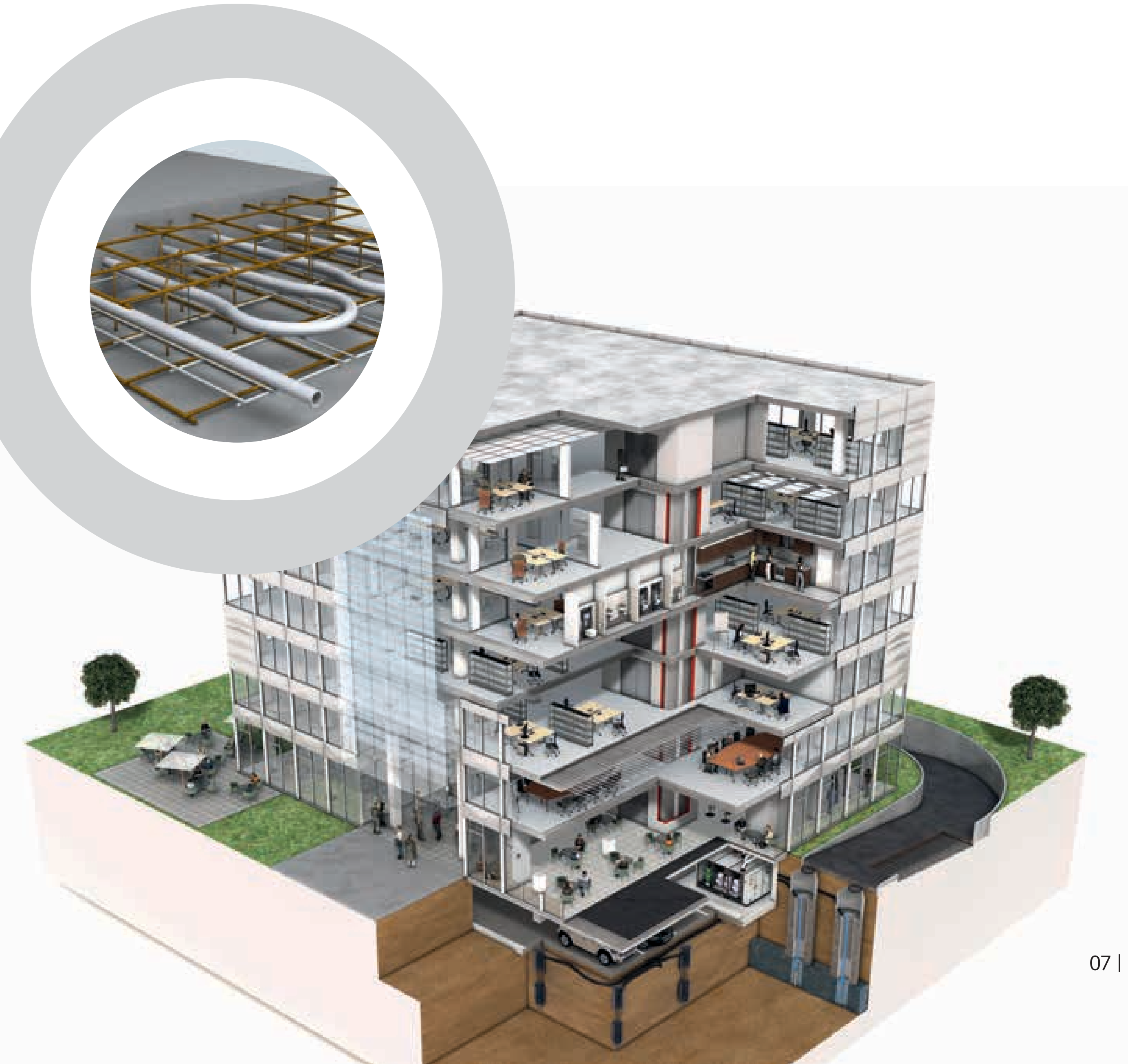
Uponor Contec TABS design basics

THERMALLY ACTIVE BUILDING SYSTEMS



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Cooling and heating sources

General boundary conditions and basic principles

For the selection of conventional cooling and heating devices, it is important to note that the temperature level of TABS will be close to room temperature. Taking into account the control characteristics and the envisaged output, supply temperatures will usually be in the following range:

- Cooling mode: 16 °C < $t_{V, c}$ < 22 °C
- Heating mode: 24 °C < $t_{V, H}$ < 28 °C

In terms of water temperatures, the TABS system can therefore be regarded as a high-temperature cooling system, or a very low-temperature heating system. In conjunction with appropriate refrigeration and heat generation concepts, high exergetic efficiency can therefore be achieved.

Taking into account this temperature level, low exergy factors equate to low operating costs both in cooling and heating mode.

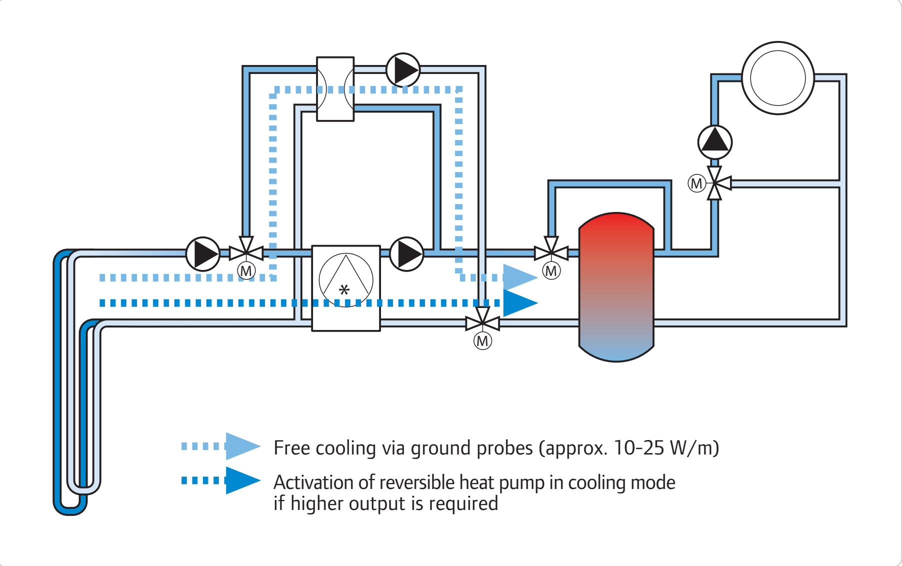
For this reason, brine/water or water/water heat pumps are recommended for heating, chillers for high-temperature cooling, and reversible heat pumps for cooling and heating. In simultaneous heating and cooling mode, both the "cold" and "warm" sides of the heat pump can be utilised in conjunction with 'buffer storage', which is generally recommended in any case. Load management requires particular attention. The system temperatures encountered provide an ideal opportunity to include renewables. Renewables are not only subsidised via the German Renewables Feed-In Act ("Gesetz für den Vorrang Erneuerbarer Energien") (EEG of 1 April 2000) and the Building Energy Conservation Ordinance ("Energie-EinsparVerordnung") (EnEV 2002 of 1 February 2002), but already feature prominently in a wide range of winning projects in architectural competitions.

The following system configurations can be used to complement TABS:

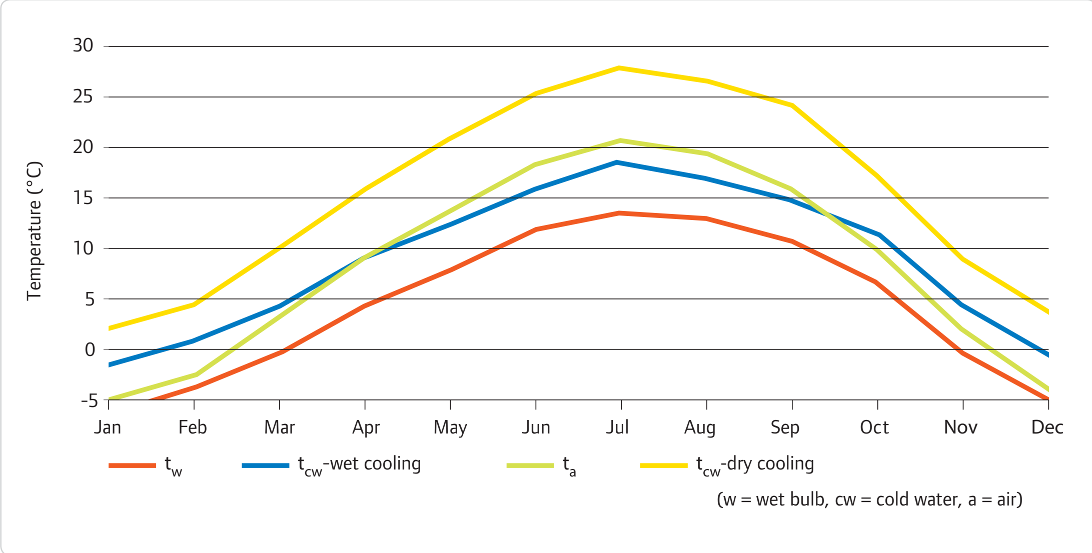
- Geothermal/groundwater: free cooling, and combination with heat pumps
- Ambient air: combination with recirculation coolers
- Solar thermal: absorption refrigerating machines with additional solar collectors

In terms of conventional cooling sources, cold water flow temperatures of 16 °C are adequate and cost-effective for compensating sensitive heat. Chillers (supplying cold water flow temperatures of 6 °C) are only recommended if additional dehumidification is required. Depending on the size of the system, it may be expedient to use separate chillers for dehumidification (approx. 6 °C) and cooling (> 16 °C). An alternative is dehumidification based on sorption, which has been used successfully for some years now.

Options for heating & cooling systems with TABS



Free cooling and combination with a reversible heat pump

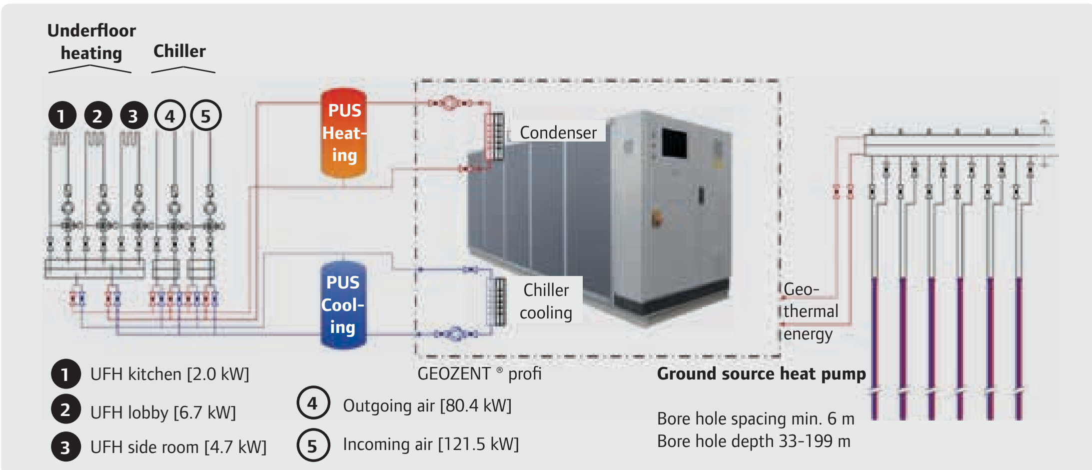


Cold water temperatures achievable with wet and dry cooling towers over the course of a year after Fackel-mayer

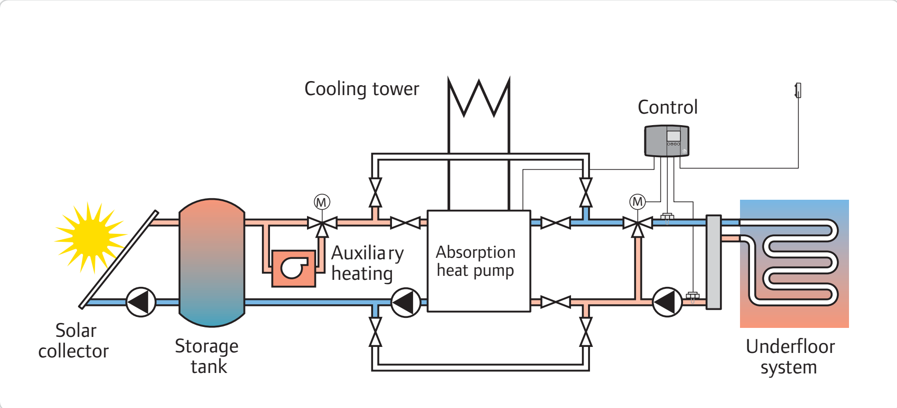
Seasonal cold water temperature levels available from the wet or dry cooler must be taken into account.

Recooling unit with pressure boosting www.dretec.de

Utilisation of recooling units for generating cold water



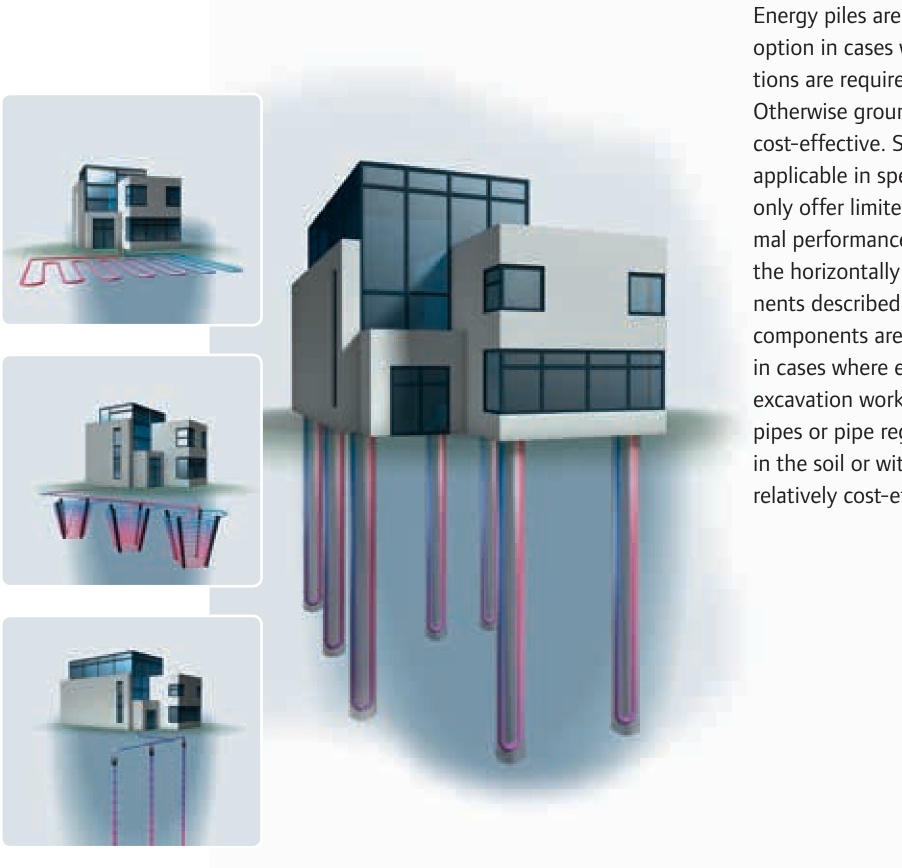
Function chart of geothermal energy supply with Geozent® profi



Cold water generation with solar thermal support

Notes on designing components for thermal utilisation of ground energy

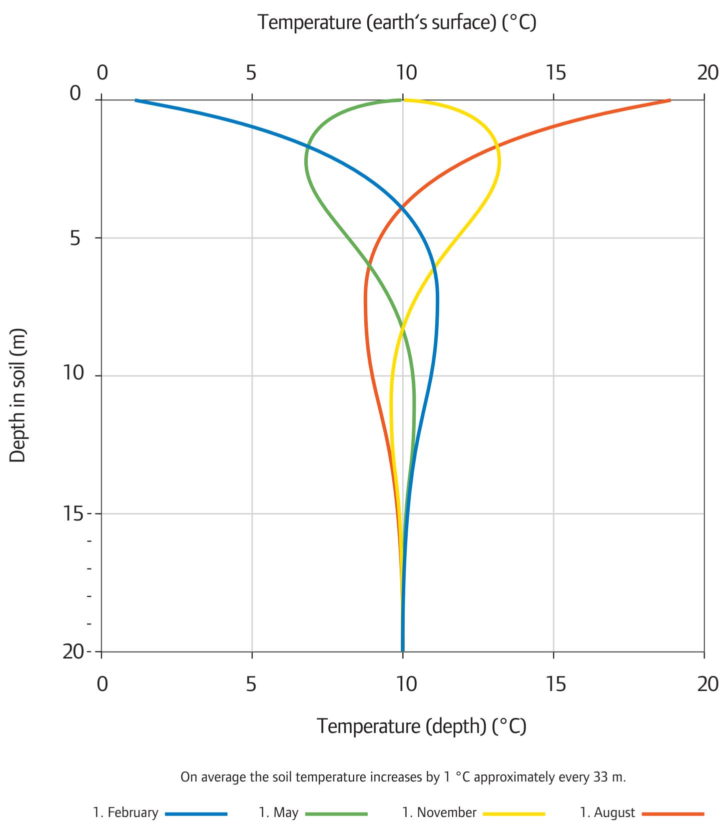
System concept
Thermal utilisation of ground energy in conjunction with TABS provides an ideal solution. On the one hand, it can make a contribution to environmental protection; on the other hand operating costs are reduced through the use of renewable energy. A distinction is made between horizontal and vertical collectors in the ground.



From a depth of approx. 10 metres, ground temperatures are relatively constant over the seasons, leading to more stable operating conditions for vertically oriented components. Energy piles are the preferred option in cases where pile foundations are required for the building. Otherwise ground probes are more cost-effective. Slotted walls are only applicable in special cases and can only offer limited depth. Their thermal performance is similar to that of the horizontally oriented components described below. Horizontal components are worth considering in cases where extensive ground excavation work is required, so that pipes or pipe registers can be laid in the soil or within a blinding layer relatively cost-effectively.

Unlike vertical components, the long-term performance of ground collectors is affected by temperature fluctuations. The performance of floor slab cooling systems is affected by possible thermal coupling with the basement, so that in both cases closer consideration is required. For these reasons, ground collectors are usually used for 'heat pump heating mode', and floor slab cooling systems for free cooling or 'heat pump cooling mode' (refrigerating machine). The performance potential of a ground collector located adjacent to a building would be inadequate for space cooling during the summer, while using a floor slab cooling system as a thermal absorber in winter involves frost risk for the foundation.

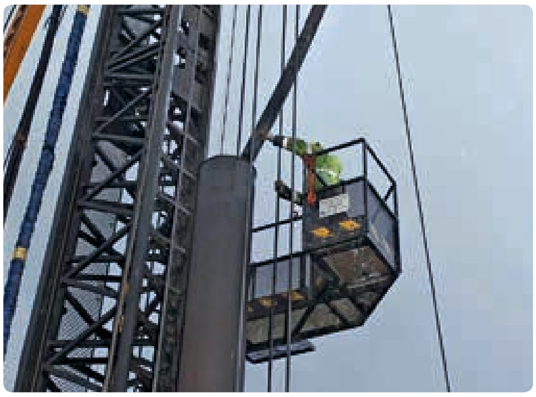
In addition to these heat exchangers, short or long-term ground stores (thermal energy storage according to VDI 4640) can be used, although these involve significantly more excavation and insulation work.



Geothermal components in practice

Installing the reinforcing cages

Concreting procedure of the in-situ piles



Filling pipe for concreting

Supervision of the pile assembly

Assembly of a bore pile

Prefabricated concrete bored pile

Basic design principles

Proper design of ground heat exchanger systems requires an understanding of the thermal interrelationships in the ground near the surface. Any design calculations should therefore be preceded by a geological survey in order to determine geological ground conditions at the site. From these survey results, the different thermal ground parameters required for an accurate calculation of the ground heat exchanger configuration can be derived.

For large systems that have to provide high security of supply, complex simulation calculations are recommended. These can provide insights into sustainable operation, possible effects on the geothermal balance of adjacent land, and any chemical/physical changes in the ground or groundwater.

For the design of ground collectors, floor slab cooling systems or foundation storage systems, ISO EN 13370 ″Heat transfer via the ground – calculation methods″ and other guidelines can be used. This standard deals with the heat transfer of floor slabs, including thermally-active slabs, via the ground.

By modifying the system parameters (pipe registers, insulation, geometric dimensions of the building etc.) and system management variables, statements about the thermal performance of a floor slab cooling system during the summer can be derived.

VDI guideline 4640 ″Thermal use of the underground″ can be used for estimating system performance in heating mode. This document also contains information regarding approval procedures and environmental boundary conditions. However, a revision of this guideline for summer cooling is still outstanding.

The following tables provide an overview of the thermal extraction performance of ground types.

	Unit	Sand	Clay	Silt	Sandy clay
Water content	% Vol.	9.3	28.2	38.1	36.4
Heat conductivity	W/mK	1.22	1.54	1.49	1.76
Specific heat capacity	J/kg K	805	1.229	1.345	1.324
Density	kg/m³	< 15	1.816	1.821	1.820

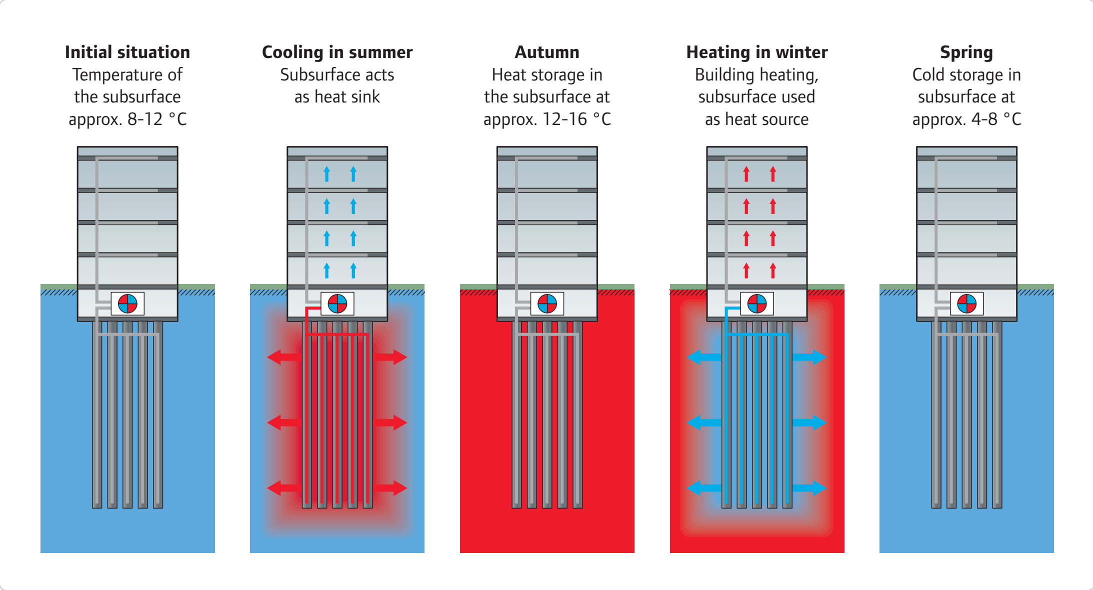
Physical properties of the characteristic soil types (source: VDI 4640)

Accurate modelling and more detailed calculations are also recommended in the following cases:

- Deviations of heat pump operating times from those mentioned above
- Higher heating energy demand for hot water generation
- Ground effect of heat input through space or commercial cooling or solar thermal recharging (annual balance method)
- Strong groundwater influence (drift velocity between 10 m/a and 150 m/a).

The above-mentioned guide values for thermal extraction performance are not necessarily directly transferable to summer operation. The following factors may lead to differences between extraction and input performance:

- Starting from an undisturbed ground temperature of more than 10 °C, in heating mode the ground adjacent to the probes or pipes may cool down as far as freezing point. This temperature difference is greater than the thermally useful range in summer operation. For space cooling, the water temperature should not exceed approximately 17 °C, so that soil temperature has to be lower.
- In winter mode, an ice shield will form around the probe or pipe that influences heat conduction. In summer mode, heat conduction is characterised by moist or dry soil.
- Soil layers near the surface are subject to strong climatic influences, so that classic ground collectors that are not located below buildings should not actually be called geothermal, but solar thermal components. For floor slab cooling systems, these climatic influences only affect input performance in the edge zone, but on the whole, the efficiency of this type of component is determined by soil characteristics, including groundwater.

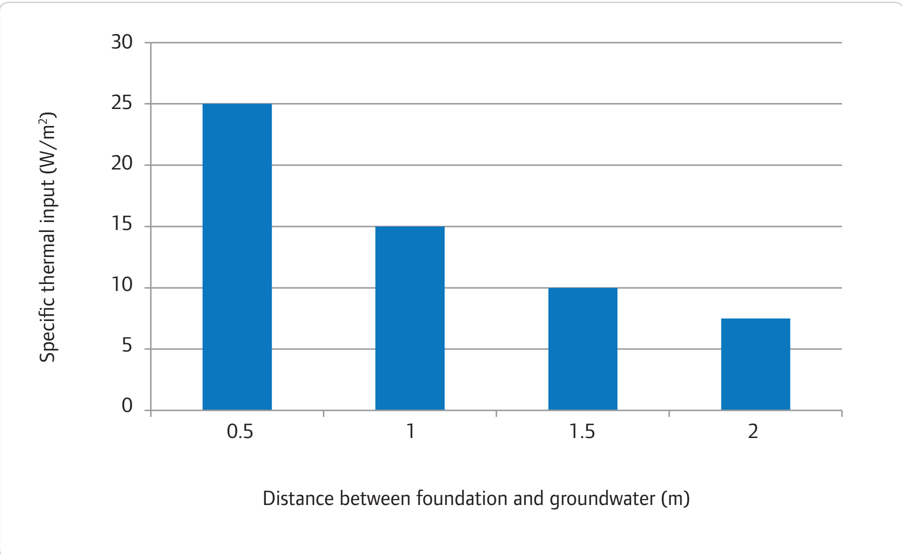


Energy piles: thermal utilisation of the subsurface

Differences in temperature lift between heating and cooling mode (ground probes)

For the purpose of estimating the long-term performance of ground probes and energy piles, it is therefore recommended to reduce the thermal extraction performance values quoted in VDI 4640 by 30 %.

For floor slab cooling systems, the following guide values can be used, based on theoretical considerations and practical experience including measurements:



Specific thermal input (~ cooling load density) of a floor slab cooling system depending on the distance between groundwater and foundation (moist cohesive floor/saturated gravel or sand)

According to the current state of knowledge, the following design recommendations can be given for floor slab cooling systems:

- Specific input performance is strongly dependent on the groundwater level. Saturation, due to high ground water levels, of soil layers below the foundation increases heat conduction. This can lead to long-term cooling outputs that are similar to ceiling performance with concrete core activation, or floor performance with underfloor cooling.
- The pipe spacing should not exceed 15 cm.
- Regeneration phases during periods when the system is switched off or during periods with reduced or no cooling demand (cool summer days) improve performance potential.
- Performance may be higher if basement spaces are thermally coupled. However, if basement temperatures rise, long term performance will be reduced (similar to the effect of increasing soil temperature).

Thermal calculations

Calculation of output for the steady- state case

Uponor will provide a project-specific calculation based on a given slab construction.

Unlike a dynamic approach that, for example, takes into account the thermal capacity of structural components, the steady-state approach represents a snapshot indicating performance due to heat transmission for the specified temperatures and a given ceiling construction.

The main parameters that determine the performance of a surface system are the heat transfer coefficient at the ceiling or floor, the acceptable minimum and maximum surface temperatures, and the available area.
Steady-state performance can be calculated based on standards for heating systems in buildings (ISO 11855).
Design calculations for a given construction are based on the adjacent calculation parameters.

If TABS is used for cooling and basic heating, it is necessary to take into consideration that usually the amount of mass flow will not change between these two usages (same pump performance in winter and summer).
Because of this, water mass flow should be based on the cooling function. In order to achieve high performance with water temperatures that are as close to room temperature as possible, the difference between supply and return temperature should be small (2-5 K).

The required water mass flow is determined based on the maximum output (40-60 W/m²) and the spread.
The maximum length of the cooling/heating circuit is then determined based on the maximum acceptable pressure loss.

New buildings such as passive houses have a very low heating or cooling demand. Their hydraulic design should take into consideration a turbulent mass flow with a Reynolds number above 2300. If necessary, a smaller pipe dimension, longer pipe loops or a lower mean water temperature must be designed.

Calculation parameters

- Cooling
  - Supply temperature: 16°C
  - Return temperature: 20°C
  - Room temperature: 26°C
  - Relative humidity: 50 %
  - Heat transfer coefficient:
    floor = 7 W/m²K; ceiling = 10.8 W/m²K

- Heating
  - Flow temperature: 28°C
  - Room temperature: 26°C
  - Heat transfer coefficient:
    floor = 10.8 W/m²K; ceiling = 6 W/m²K

All slabs feature the following system:
System: Uponor Contec
Pipe: PE-Xa 20
Pipe spacing: 150 mm

Simplified model calculation based on finite difference method (FDM)

In general, calculations of output for the steady-state case are carried out to recognize the maximum power capacity that can be achieved under given boundary conditions. This provides important information to design the hydraulics of the system. To ensure accurate chiller sizing, dynamic simulations need to be carried out due to the high thermal inertia of TABS. Currently, Uponor uses methods internally that are described in the related standards, such as ISO 11855, to perform semi-dynamic calculations. The internal Uponor SST (Simple Simulation Tool) for TABS can be used to model the system.

As described in ISO 11885-4 there are different calculation methods.

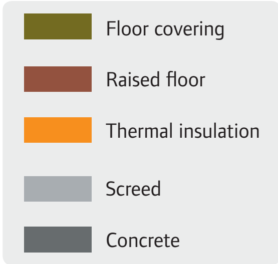
1. Rough sizing method based on standard calculations (error: 20-30 %)
2. Simplified method using diagrams (error: 15-20 %)
3. Simplified model based on finite difference method (FDM) (error: 10-15 %)
4. Detailed energy simulation of building (error: 6-10 %)

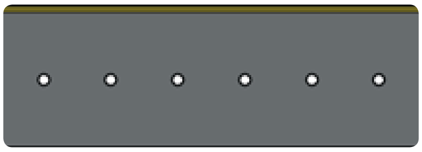
It can be seen that the simplified model method based on FDM performs calculations with an accuracy that comes close to a detailed simulation.
The finite difference method is based on the calculation of heat balance for each thermal node defined within the slab and the room. Information about the structure (walls, windows), the TABS system and location must be defined for this calculation. Internal loads and maximum cooling power can be defined for every hour of the day for a defined room.

The SST for TABS is able to calculate a semi-dynamic temperature profile (operative temperature) for a single zone and allows conclusions about the sizing of TABS and the required chiller capacity taking into consideration different operation modes.

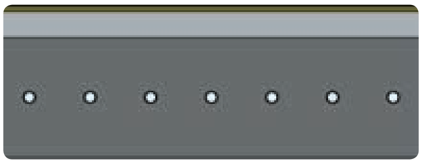
Ceiling configurations

Ceiling configurations without insulation or air gap are ideal for maximising the output of TABS. The following ceiling design variants are suitable for this purpose:





Concrete slab

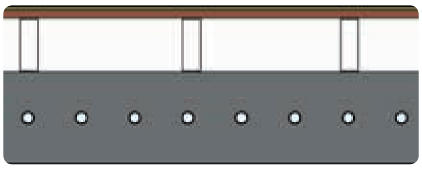


Concrete slab with bonded screed

Concrete slabs with only a thin floor covering or bonded screed deliver a maximum heating or cooling capacity upwards into the room.

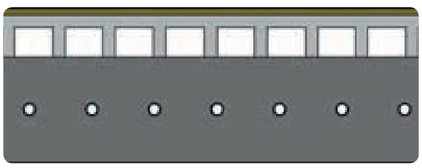
Concrete slab with impact sound insulation

Impact sound insulation reduces output via the floor. However, this design option is acceptable in applications where mainly the effect of cool ceilings is utilised.



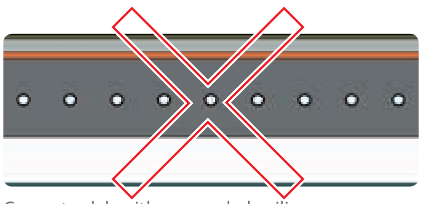
Concrete slab with raised floor

For a raised floor, the same considerations apply as for a floor with impact sound insulation. This type of ceiling construction is popular because power supply and EDP 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 have to be used for the underfloor installations.

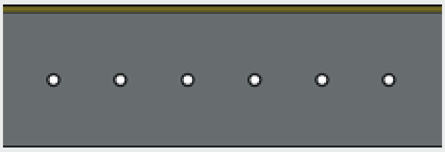


Concrete slab with suspended ceiling

Suspended ceiling are normally unsuitable in conjunction with concrete core activation. The false ceiling undermines the operating principle of concrete core activation. Specific applications include, for example, removal of heat emitted by lighting systems from ceiling voids.

Output from a concrete slab without insulation

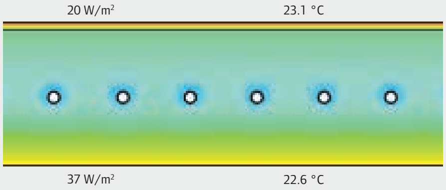
A finite element calculation using a program for 2-dimensional heat transfer illustrates the temperature distribution in the structural component.



Carpet : 0.015 m, $R_{\lambda,B}$ = 0.10 m²K/W

Concrete : 0.300 m

Cooling mode



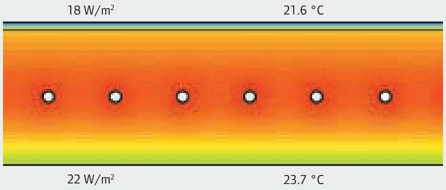
Calculation parameters

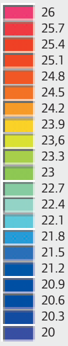
Flow temperature	: 16°C
Return temperature	: 20°C
Room temperature	: 26°C
Rel. humidity	: 50 %

Cooling output

Output via floor	q_{fl} = approx. 20 W/m²
Output via ceiling	q_{ce} = approx. 37 W/m²
Total output	q_t = approx. 57 W/m²

Heating mode





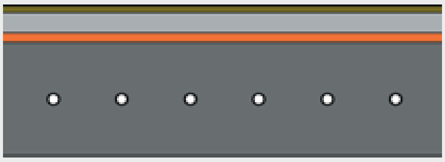
Calculation parameters

Flow temperature	: 28°C
Room temperature	: 20°C

Cooling output

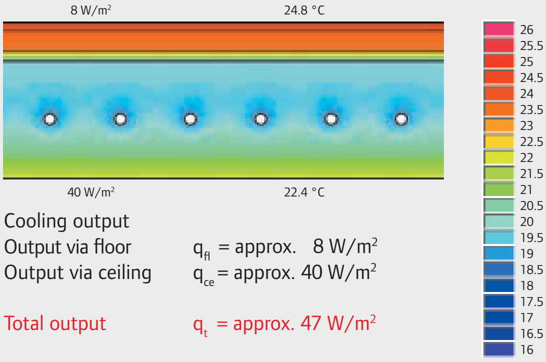
Output via floor	q_{fl} = approx. 18 W/m²
Output via ceiling	q_{ce} = approx. 22 W/m²
Total output	q_t = approx. 40 W/m²

Thermal output of a concrete slab with step-sound insulation layer



Carpet	: 0.015 m, $R_{\lambda,B}$ = 0.10 m²K/W
Screed	: 0.045 m
Impact sound	: 0.020 m
Concrete	: 0.250 m

Cooling mode



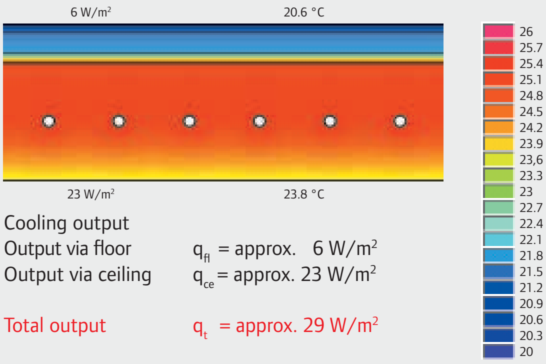
Calculation parameters

Flow temperature	: 16°C
Return temperature	: 20°C
Room temperature	: 26°C
Rel. humidity	: 50 %

Cooling output

Output via floor	q_{fl} = approx. 8 W/m²
Output via ceiling	q_{ce} = approx. 40 W/m²
Total output	q_t = approx. 47 W/m²

Heating mode



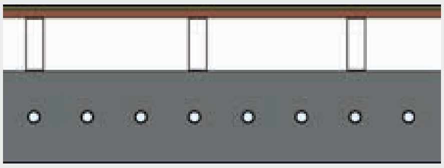
Calculation parameters

Flow temperature	: 28°C
Room temperature	: 20°C

Cooling output

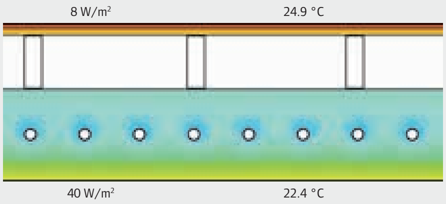
Output via floor	q_{fl} = approx. 6 W/m²
Output via ceiling	q_{ce} = approx. 23 W/m²
Total output	q_t = approx. 29 W/m²

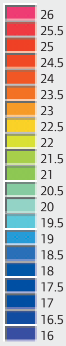
Output from a concrete slab with raised access floor



Carpet	: 0.015 m, $R_{\lambda,B}$ = 0.10 m²K/W
Panel	: 0.020 m
Air space	: 0.150 m
Concrete	: 0.250 m

Cooling mode





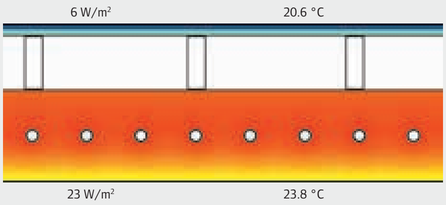
Calculation parameters

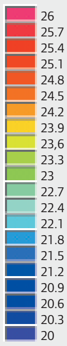
Flow temperature	: 16°C
Return temperature	: 20°C
Room temperature	: 26°C
Rel. humidity	: 50 %

Cooling output

Output via floor	q_{fl} = approx. 7 W/m²
Output via ceiling	q_{ce} = approx. 40 W/m²
Total output	q_t = approx. 47 W/m²

Heating mode





Calculation parameters

Flow temperature	: 28°C
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Cooling output

Output via floor	q_{fl} = approx. 6 W/m²
Output via ceiling	q_{ce} = approx. 23 W/m²
Total output	q_t = approx. 29 W/m²

Reduction in output through acoustic measures, insulating layers or voids

Floor construction

As demonstrated in the above calculations, building designers need to be aware of the fact that output via the floor is reduced significantly if a raised floor is installed. This is particularly important if the system is meant to cover a large heating load. The necessity of a raised floor should be considered very carefully. Conventional impact sound insulation also obstructs heat emission via the floor. If impact sound insulation is essential, materials with adequate impact sound characteristics, yet good heat transmission, should be selected.

Ceiling construction

It should be noted that, due to their impact on heat transfer, enclosed suspended ceilings are usually not suitable in conjunction with TABS. Convection heat transfer is restricted and subject to long time lags. Acoustic plaster covering the whole ceiling has the same effect as a suspended ceiling.

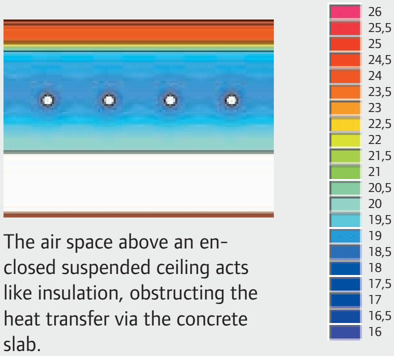
The TABS system can achieve maximum output in ceilings without any lining (plaster). However, the acoustic performance of such exposed ("hard") surfaces is less favourable. To comply with acoustic requirements, the installation of ceiling panels should be considered. Naturally, these devices also have some effect on the performance of TABS, depending on their area coverage. The same applies to suspended louvered ceilings. While performance is reduced, general functionality is maintained.

Important design advice: an acoustician should be involved in the design phase

Depending on the free area, performance is reduced by up to 30 % for up to 60 % enclosed ceiling (see "Acoustics" chapter). In order to avoid loss of performance, it may be useful to consider implementing acoustic measures on walls, rather than the ceiling. Further options for locating acoustic measures include office cabinets, partitions and furniture.

In future, new sound-absorbing structures may become available that can be installed on the ceiling without significantly restricting thermal output via the ceiling.

Suspended ceiling



The air space above an enclosed suspended ceiling acts like insulation, obstructing the heat transfer via the concrete slab.

Dynamic considerations

Conventional heating/cooling systems can be designed to deal with heating or cooling loads as soon as they arise. In principle, such systems can be designed based on steady-state calculations.

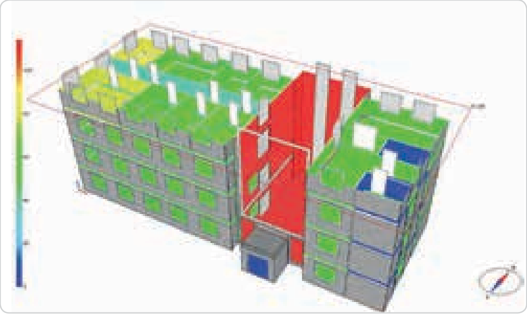
In contrast, TABS will not be able to fully dissipate loads at all times. Diurnal temperatures will therefore vary depending on the available thermal mass and actual cooling loads. To estimate these fluctuations, the variation of loads and their dissipation over time must be considered. The ability to make explicit statements during the design phase about how a building with TABS will behave, requires calculations that take into account the inertia of the thermal mass of the building. It is therefore important to consider the dynamic behaviour of all factors that influence the temperatures inside the building.

These parameters include:

- The weather (in particular solar radiation and ambient temperatures)
- Structural aspects (heavy or light-weight construction, heat transfer coefficient of the façade and shading devices)
- Internal loads (from occupants, lighting and equipment)
- User behaviour and perhaps further significant factors

In order to predict potential violations of the comfort zone and their frequency, the dynamic behaviour of all the parameters listed above should be taken into account. This can be achieved using thermal simulation.

Simulation software is no substitute for design advice from a building services or building physics specialist.



Cooling load simulation of an office building

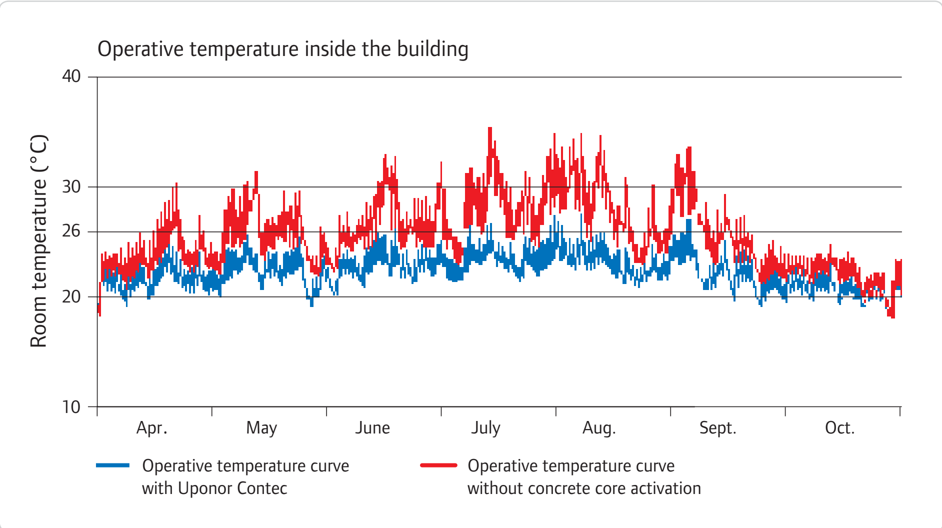
Thermal building simulation for different building types

Based on simulation results, the thermal behaviour of different building types is explained. The room or operative temperature (dry resultant temperature), with or without TABS, during an extreme hot spell is examined.

The program TRNSYS version 15 was used for the dynamic calculations described below. The associated multi-zone building model (TRNSYS type 56) already contains a module for entering the boundary conditions for TABS. The calculations are based on the Uponor Contec system (PE-Xa pipe with dimensions of 20 mm, pipe distance 150 mm). The system covers 80 % of the floor area.

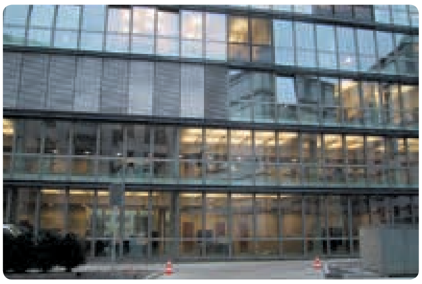
The following charts show different temperature curves illustrating the thermal behaviour of a space during a 5-day hot spell. The assumed external temperature is also shown. It fluctuates between 16 and 32 °C. The charts do not show the high direct solar radiation assumed for the simulation, which naturally is another crucial factor for the thermal behaviour of the building under the extreme conditions examined in this example.

The simulation focuses on the cooling mode, since this is the main area of application for TABS.



Comparison of simulated dry resultant temperature curves: In summer, concrete core activation can effectively counteract overheating of the building – apart from isolated occasions, the room temperature remains below 26 °C

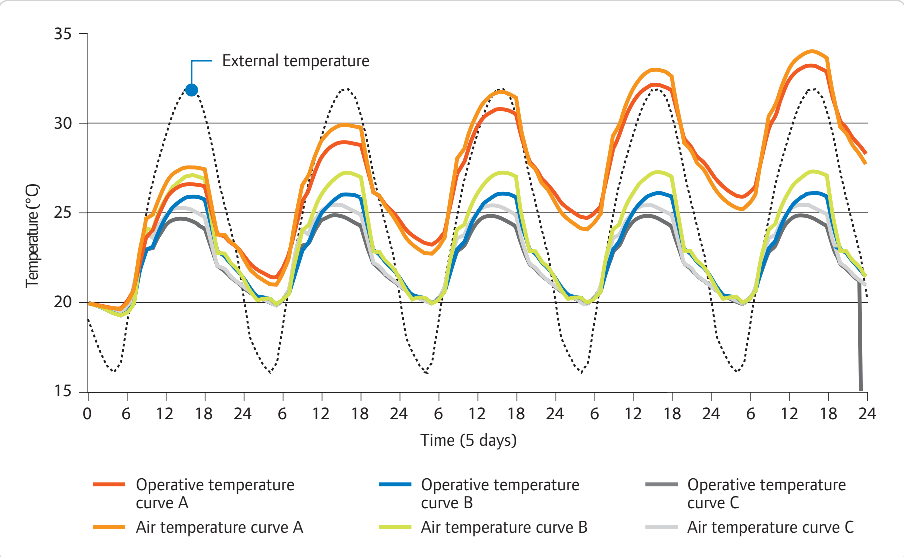
Thermal building simulation for building with floor-to-ceiling glazing



The first building to be examined is a modern office building with floor-to-ceiling glazing (low-E glazing with a heat transfer coefficient U = 1.1 W/m²K, total solar heat gain coefficient g = 0.6). The thickness of the concrete slab is 300 mm, with a raised access floor on top. The floor is covered with carpet. Apart from the heavy-weight ceiling, the rest of the interior is of light-weight construction. The partitions consist of plaster-board with mineral fibre insulation.

The building is equipped with automatic shading devices (external blinds, shading reduction factor z = 0.25), which limit the presence of direct solar radiation. The space examined is a south-facing office with a floor area of 20 m². Internal loads during the occupied period (8am-6pm) are assumed to originate from the heat gain from 2 persons, 2 PCs with monitor, a printer and lighting.

Different variants were examined:
A) No TABS, natural ventilation
B) TABS, natural ventilation
C) TABS plus mechanical ventilation



A) Some form of cooling is essential in this building. During the 5-day hot spell, the temperature inside the building reaches 34°C.

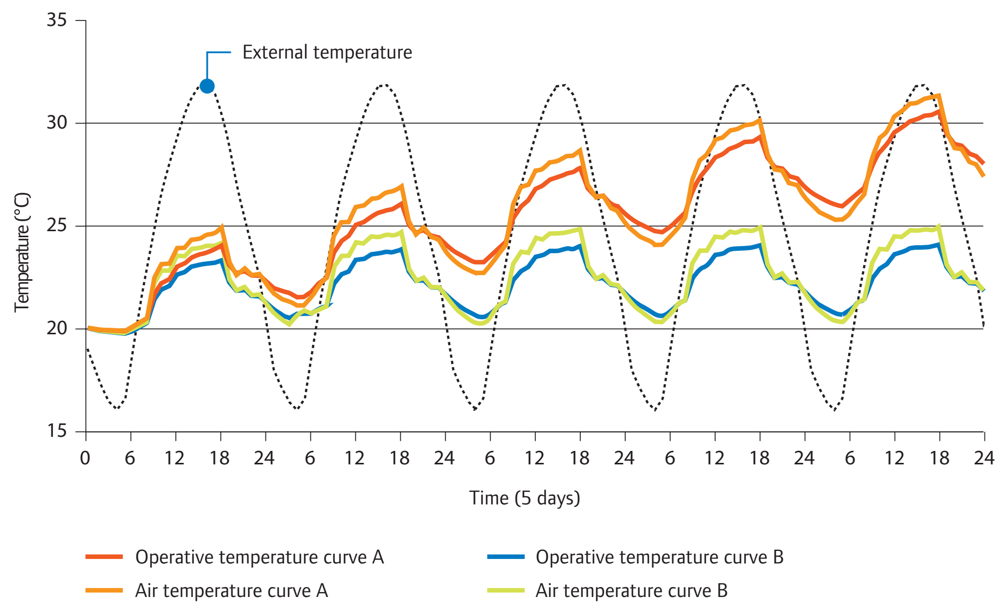
B) TABS is able to prevent successive temperature rise inside the building. The temperature inside the building remains approximately within the range of 20 to 26°C.

C) If additional mechanical ventilation with 2 air changes per hour and a supply air temperature of 18°C is used, the temperature inside the building can be maintained within an even narrower temperature range.

Thermal building simulation for a building with high thermal mass (façade with double-skin masonry wall)

The second example is an office building with high thermal mass in the form of heavy-weight ceilings and external walls. Instead of floor-to-ceiling glazing, the building features a double-skin masonry wall construction (solid brick wall U = 0.4 W/m²K). The window area ratio (low-E glazing U = 1.3 W/m²K, g = 0.59) of the façade is approximately 60 %.

The concrete slab with a thickness of 240 mm is covered with bonded screed and carpet. The internal walls are constructed from sand-lime brick with a thickness of 11.5 cm. Internal loads during the occupied period (8am-6pm) are assumed to originate from the heat gain from 2 persons, 2 PCs with monitor, a printer and lighting.



A) Due to the higher thermal mass and the smaller window area ratio, compared with the previous building this building is less sensitive to internal and exterior loads. Nevertheless, by the 5th day of the hot spell, the internal temperature has reached more than 30 °C.

B) Concrete core activation prevents successive temperature rise inside the building. Due to concrete core activation, the operative temperature inside the building remains within a narrow range of approx. 21 to 24 °C.

When should simulation be used?

The advantage of tools such as simulation programs is that they can help optimise the overall concept and uncover potential design weaknesses. Simulation is always recommended for buildings with large load fluctuations, potentially high moisture load and exposed room locations. However, simulation is not necessarily required for all buildings with TABS.

Based on the experience gained in the design and operation of existing systems, statements about the likely performance of TABS in the respective building can be made without project-specific dynamic calculation. For example, steady-state calculations provide information about the achievable output and enable dimensioning of the pipes. Most existing projects with TABS have been constructed on this basis. Provided the design remains within the limits set by this technology, satisfactory function and a gain in comfort is guaranteed.

An adjustment phase after commissioning of the TABS system is likely to be required with or without simulation.

Conclusions from the above simulations

- Uponor Contec can be used for different types of building
- In buildings with high loads, TABS should at least be able to compensate a base load, so that any additional ventilation system that may be required can be designed smaller
- Due to advantageous investment and operating costs, TABS can provide a comfortable working environment in buildings where normally, for cost reasons, no cooling would be provided

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