Life cycle cost comparison of TABS vs. other HVAC (UK)

TECHNICAL BROCHURE

10 | 2018

Contents

This report is based on an internal Uponor study "Full cost comparison of TABS vs. other HVAC" conducted in cooperation with Equa Simulation Finland Oy and Mott MacDonald Limited, UK.

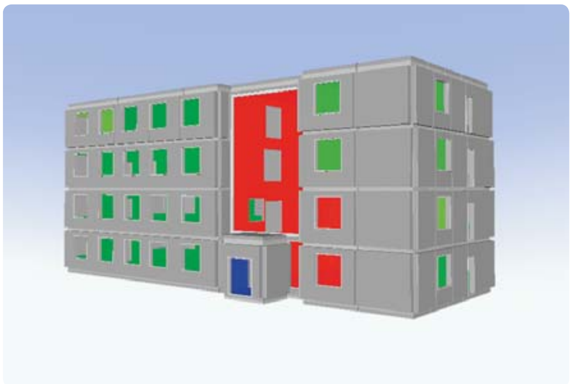
The results are valid explicitly only for the used boundary conditions and may not be extrapolated for other instances.

Introduction

A Thermally-Active Building System (TABS) is a combined cooling and heating system with pipes embedded in the structural concrete slabs or walls of non-residential buildings. The TABS operates at temperatures close to ambient which facilitates the integration of renewable and free cooling sources. Although the TABS is a mature and well proven technology in Central Europe due to energy savings and low investment and operating costs compared to other traditional air-based technologies, there is still limited evidence in the UK. The present study compares a Life Cycle Cost (LCC) analysis of an office building with TABS to a traditional convective all-air conditioning, fan coils, displacement ventilation and chilled beam solution.

The Building Energy Simulation (BES) data used to collate the report is provided by Equa Simulation Finland Oy. The HVAC systems were selected based on what is commonly specified in the UK. Cost analysis was performed by Mott MacDonald Limited. Using outputs from thermal modelling by Equa carried out on each case, Mott MacDonald created design concepts and quantity survey for each mechanical services method. Costs were obtained from a variety of sources, including manufacturers, construction economists, and Mott MacDonald's own expertise.

The cooled ceiling slab accumulates the thermal loads from the room or direct sunshine



Base building, south-east view

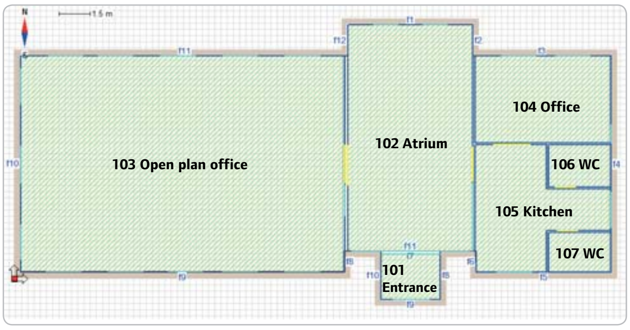
Base building

Building data

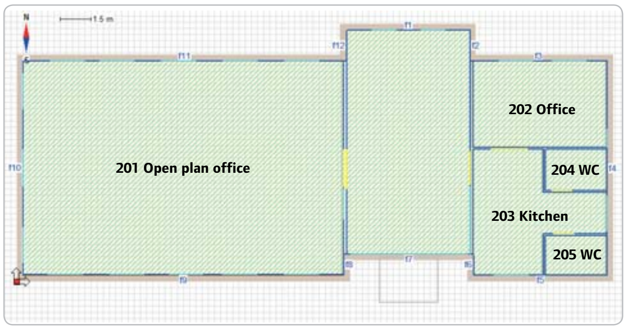
Building size	1 000 m²
Length/Width/Height:	29 /11/12 m
Storey height/No. of storeys	2.8 m/ 4
Location	London

Room partitioning

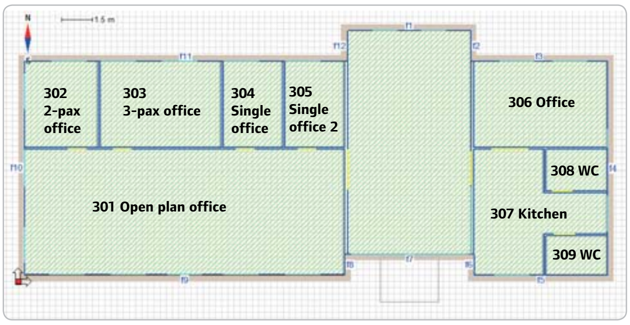
Single, open plan offices and an atrium to suit all types available on the market.
Figures below show floor plans of the building, with the room numbers and names as used in LCC calculation.



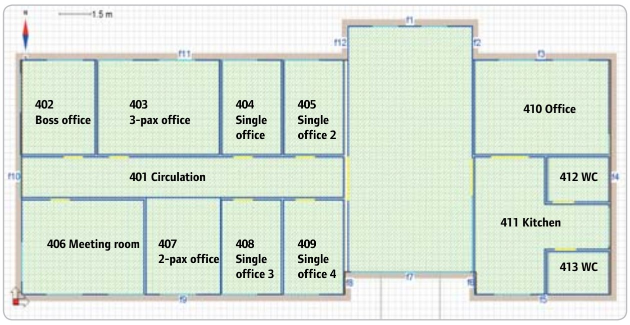
Base building, ground floor



Base building, first floor



Base building, second floor



Base building, third floor

Building shell and core

- External wall: U-value 0.20 W/m²K
- Roof: U-value 0.21 W/m²K
- External floor against ground: U-value 0.19 W/m²K
- Internal wall construction: U-value 1.435 W/m²K
- Internal slab (floor) construction: 300 mm concrete with TABS pipes at 85 mm from the soffit, U-value 1.59 W/m²K
- External window glazing U-value 1.56 W/m²K, g value 0.357, including frame. External solar shading.
- Okalux window glazing U-value 2.439 W/m²K, g value 0.195, including frame. External solar shading.

Setpoints and internal loads

- Room temperature in summer during occupied period: 25 °C
- Room temperature in winter during occupied period: 21 °C
- The required fresh air volumes during occupancy in office spaces: 12 l/s/person
- The equipment loads: 10 W/m²
- The occupant loads: 90 W/person sensible (occupation in offices 8 m²/person and 4 m²/person in meeting room)
- The lighting loads: 10 W/m²
- The meeting room VAV CO2-setpoint is 800 ppm
- Cooling is not provided to toilets

	Ground floor	First floor	Second floor	Third floor	Total
Floor area	319 m^2	253.6 m^2	253.6 m^2	253.6 m^2	977.6 m^2
No. of rooms	7	5	9	13	34
No. of occupants	22	22	22	22	88

Internal loads are not taken into account when dimensioning for heating but for simulation purpose

Description	Heating load	Cooling load
Room average (excluding the Atrium)	18.5-50.1 W/m^2 avg 28.6 W/m^2	47.2-73.7 W/m^2 avg 55.1 W/m^2
The most unfavourable rooms for heating: Atrium + entrance	80 W/m^2	
The most unfavourable rooms for cooling: Atrium		89 W/m^2
Total	31,660 W	55,720 W

System and test cases

	 Thermally active building system (TABS)	 TABS with ground source heat pump (GSHP)	 Fan coil units (FCU)	 Displacement ventilation (DV)	 Chilled beam (CB)
Heat source	Boiler	GSHP	Boiler	Boiler	Boiler
Heat sink	Chiller	GSHP + free cooling	Chiller	Chiller	Chiller
Complimentary room units	Convectors in selected rooms	Convectors in selected rooms	–	–	–
Ventilation	Mechanical minimum fresh air	Mechanical minimum fresh air	Mechanical minimum fresh air	Mechanical	Mechanical
Description	TABS for cooling and base load heating supplemented by mechanical minimum fresh air ventilation with a heating coil and heat recovery. Gas condensing boiler and central chiller as a heat source/sink. Complimentary convector radiators only in six rooms (corner room or top floor) which couldn't be fully covered with TABS capacity.	TABS with ground source heat pump (GSHP): The same as option 1, but boiler/chiller is replaced by a ground source heat pump (GSHP) with bore holes, which work to certain extent of summer period in a free cooling mode.	AC fan coil for cooling and heating supplemented by mechanical minimum fresh air ventilation with a heating coil and heat recovery. Gas condensing boiler and central chiller as a heat soucre/sink.	Displacement ventilation with central AHU for heating, cooling and ventilation using heat recovery. Central water chiller and a gas boiler. Reheater box is put locally in zones.	Active chilled beam provide cooling and heating, mechanical ventilation with a heating coil and heat recovery. Central water chiller and gas condensing boiler.

The systems were selected by Uponor based on what is commonly specified in the UK

NOTE!

The mechanical minimum fresh air ventilation system was introduced to create the same indoor air quality (IAQ) condition for all compared cases. Toilets in all cases are equipped with an exhaust fan only (no air supply).

Standard default control algorithms are applied for the fan coil, beam and displacement ventialtion cases.

The global cost comparison is based on the above mentioned complete HVAC schemes.

TABS model and control strategy

There are two separate TABS circuits (zones), basically one for each facade (south/north). The rooms which have the largest heating requirement have supplementary convector radiators (for peak heating load). The list of zones with both TABS and convectors are:

- 104 - Office
- 302 - 2-pax office
- 409 - Single office-4
- 402 - Boss single office
- 406 - Meeting room
- 410 - Office

The following zones do not have the TABS:

- 101 - Entrance and all toilets: convectors
- 102 - Atrium: a radiant underfloor heating/cooling

1. Outside temperature compensated supply water temperature control

This core control part determines a supply water temperature setpoint range as a function of the mean outside air temperature for last 24 hours and the current heating and cooling curves are used. In both circuits (south and north zone) there are two separate heating and cooling curves, one for weekdays and one for weekend. Both circuits have cooling and heating limits for weekend and weekdays.

2. Sequence control of zone supply water temperature

A standard sequence controller that controls the supply water temperature is acting on the heating and cooling valves. Depending on operating mode and operating state one or both sequences are disabled and the respective valve is closed.

3. Zone temperature feedback control

The minimum, maximum and average zone operative temperatures are determined for the previous 24 hours for both independent TABS circuits. The minimum and maximum feedback control has 1st priority. If activated the zone average feedback temperature control is not allowed.

4. Seasonal shut off for TABS heating and cooling

Based on local (and building related) heating need the TABS heating is shut off seasonally by calendar schedule when possible. The same applies also for TABS cooling.

TABS and GSHP model

Heating energy is generated with certain coefficient of performance (COP), which is based on ground temperature level and simulated annual plant temperatures (Source: RETSCREEN Engineering & Cases Textbook 2005, www.retscreen.net).

GSHP compressor has heating COP 4.84, which is based on local average ground temperature 12.2°C and average power weighted heating water temperature of 31.4°C at generation. The annual COP of GSHP system (incl. circulating pumps in the HP) in heating mode is 4.05.

Because the cooling function of the AHU was not applied, the generated cooling water temperature on supply was typically in range 21°C-22°C, which caused very high efficiency of free cooling from ground.

The TABS with GSHP has annual cooling COP 5.89 (including circulating pumps in the HP), which is based on 21.3°C (average power weighted supply TABS water temperature from HP during cooling mode) and a fact that 81% of cooling is produced by free cooling (circulation in the ground circuit).

CAFOD Headquarters, London, UK

Evaluation

The recast Energy Performance of Buildings Directive ("EPBD" Directive 2010/31/EU) requires the European Commission to establish by 30 June 2011 a comparative methodology of the EU Regulation No 244/2012 of 16 January 2012 for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. The LCC calculation is undertaken in accordance with this method in terms of whole life cost (corresponds to the term of global cost in EU Regulation No 244/2012) for a 15 year calculation period. BES modelling employed a building envelope characteristics and internal external climate load profiles typical for the UK.

Local and central plant (HVAC system items) were sized based on cooling/heating loads and ventilation rates from BES modelling, in the same method in the course of completing a mechanical scheme design.

Whole life costs for building and building elements are calculated by summing up the different types of costs (initial investment, energy, running, disposal) and applying on these the discount rate as to refer them back to the starting year, plus the residual value as can be seen below:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right]$$

with

Cg (τ) **Whole life cost** (referred to starting year τ 0)

CI **initial investment costs** for measure or set of measures j

Ca,i (j) **annual running cost** during year i for measure or set of measures j

Rd (i) **discount rate** for year I

Vf, τ (j) **residual value** of one or set of measure j at the end of the calculation period (referred to the starting year τ 0), to be determined by a straight line depreciation of the initial investment until the end of the calculation period and referred to the beginning of the calculation period.

The **residual value** is determined as remaining lifetime of a building or building system or component divided by the estimated economic lifetime and multiplied with the last replacement cost. The longer is a lifetime of a component/system the higher is the advantage and lower whole life cost. For TABS and bore hole heat exchangers with 50 years of lifetime (the same lifetime as a building), this fact creates a substantial advantage compared to other short life components.

The LCC comprises the following categories of costs

- Initial investment costs
  - Material and labour cost
  - Project management and design cost as a percentage of material cost
- Running costs (maintenance, capital for renovation/ replacement at the end of equipment lifetime)
- Energy costs
  - Utilities and fuel prices
  - Annual energy use

Life cycle cost

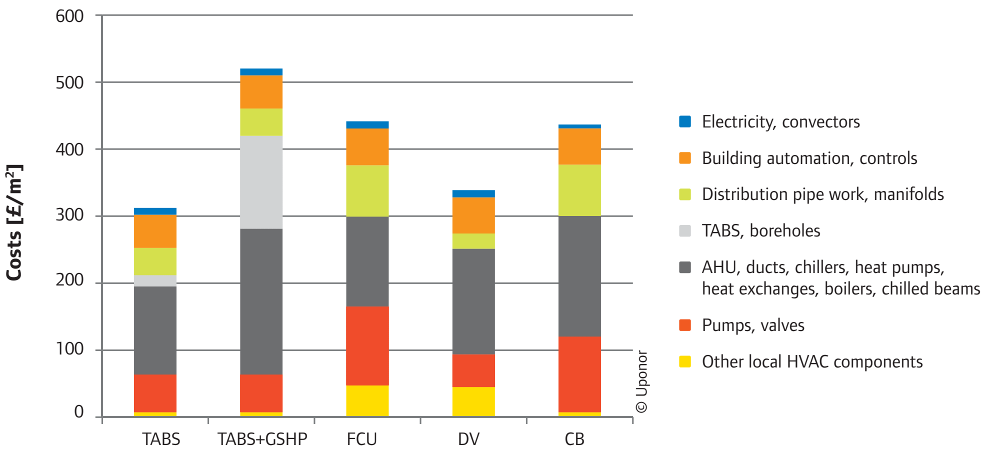
Cost of elements

Local and central plant (system items) are grouped based on the expected lifetime of each item (EN 15459 and VDI 2067 Part 1). The items in each category all have the same predicted life expectancy:

No.	Lifetime categories	Equipment lifetime
1	Electricity, wiring, convector radiators	30 years
2	Building automation, controls	12 years
3	Distribution pipe work, manifolds	40 years
4	TABS, boreholes	50 years
5	Central plant; AHU, ducts, chillers, heat pumps, heat exchangers, boilers, chilled beams, ductwork, attenuators, slot diffusers, pressurisation units	20 years
6	Pumps, valves	10 years
7	Other local HVAC components; FCU, VAV boxes, trimmer batteries, WC extract fans ductwork valves	12 years

All prices exclude Value Added Tax, or its local equivalent.

Material and installation cost



Initial investment costs of mechanical systems (material + installation) for as a sum of equipment lifetime categories

No.	Element - New Build	TABS		TAB+GSHPS		FCU		DV		CB	
		£/m²	%	£/m²	%	£/m²	%	£/m²	%	£/m²	%
1	Electricity, convectors	10	3	10	2	11	2	11	3	6	1
2	Building automation, controls	50	16	50	10	55	12	54	16	54	12
3	Distribution pipe work, manifolds	41	13	41	8	77	17	23	7	77	18
4	TABS, boreholes	17	5	138	27	0	0	0	0	0	0
5	AHU, ducts, chillers, heat pumps, heat exchangers, boilers, chilled beams	132	42	218	42	134	30	158	47	180	41
6	Pumps, valves	56	18	56	11	118	27	49	14	113	26
7	Other local HVAC components	8	2	8	1	47	11	45	13	8	2
	Total mechanical systems	312	100	520	100	442	100	339	100	437	100

Source: Mott MacDonald created design concepts (scheme) for each mechanical services method. Costs were obtained from a variety of sources, including manufacturers, construction economists (Spon's Book 2012), and consultant's own expertise both within the UK and continental Europe.

Maintenance contract cost

	TABS	TABS + GSHP	FCU	DV	CB
Annual maintenance contract	17.2 £/m²	21.9 £/m²	24.3 £/m²	18.6 £/m²	24.0 £/m²

Source: Mott MacDonald expertise. Maintenance is assumed to be 5.5% of the mechanical investment cost, excluding boreholes which are maintenance free throughout their lifetime. Annual cost covers all maintenance, inspection, and cleaning, as well as minor replacements (e.g. filters)

Utilities and fuel prices

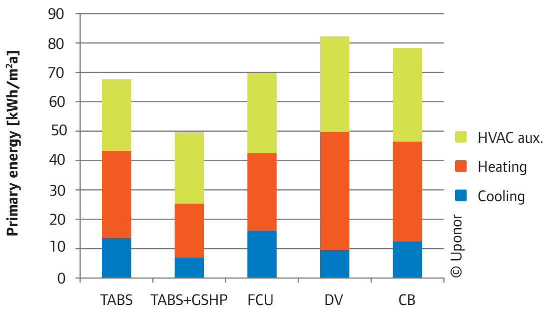
	Electricity	Natural gas
Price per kWh	£ 0.096	£ 0.027
Cost of installing a new connection	£ 10,000	£ 15,000
Annual standing charge	£ 164	£ 730

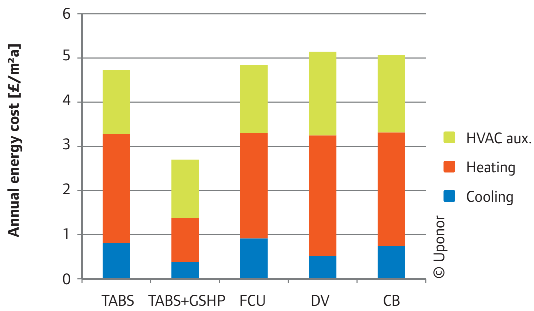
Sources: Energy prices from Energy.eu and www.DECC.gov.uk 2012, Standing charges from Compare Business Energy

Primary energy use

Annual used primary energy per m² shows a total sum that have been used by the building. Primary energy refers to the energy carriers at the beginning of the energy conversion chains (natural resources) prior to undergoing any human-made conversions or transformations. Primary energy factors: for electricity 2.55 and for natural gas 1.1 (Source: www.bre.co.uk).

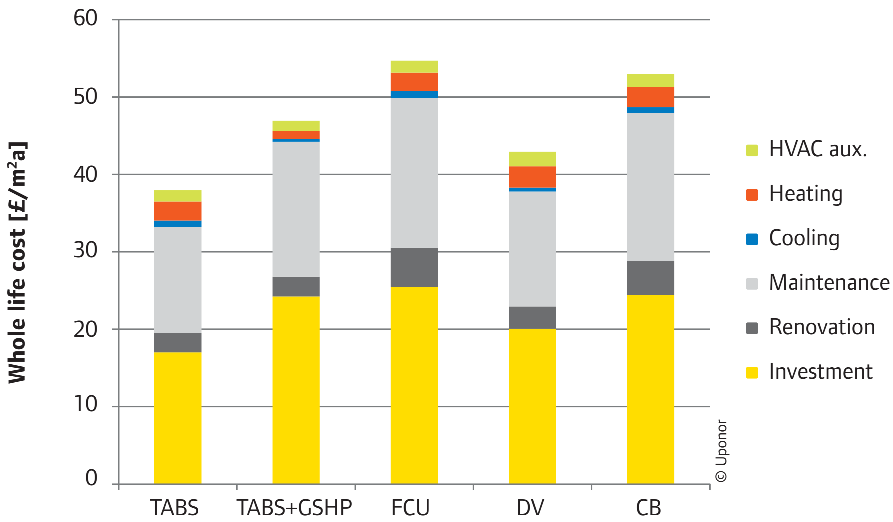
Annual energy cost per m² including cost of installing a new connection and annual standing charge calculated for 15 year of life cycle. Cost of installing a new connection for natural gas is not included in the case with the GSHP.





Whole life cost comparison

Whole life cost per m² and year, calculation for 15 years period, medium price escalation of 3% for gas and electricity. London, UK



Thermal comfort

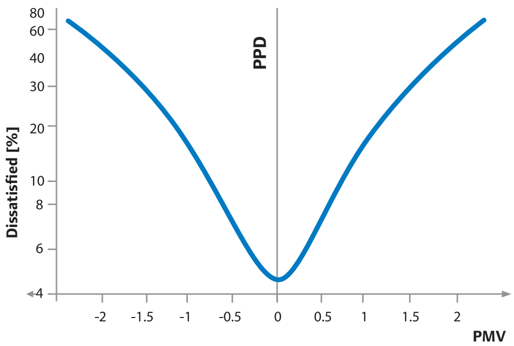
By definition ISO 7730 the thermal comfort is "That condition of mind, which expresses satisfaction with the thermal environment". Influencing parameters are; two table values describing the person's activity (Met) and clothing level (Clo) and three measured parameters describing the thermal environment at the workplace (operative temperature, air velocity and humidity)

Optimal temperature conditions

EN ISO 7730 is an international standard that can be used as a guideline to meet an acceptable indoor and thermal environment. These are typically measured in terms of predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV). PMV/PPD basically predicts the percentage of a large group of people that are likely to feel "too warm" or "too cold" (the EN ISO 7730 is not replacing national standards and requirements, which always must be followed).

PMV and PPD

The PMV is an index that predicts the mean value of the votes of a large group of people on a seven-point thermal sensation scale (see table below), based on the heat balance of the human body. Thermal balance is obtained when the internal heat production in the body is equal to the loss of heat to the environment.



PMV	Predicted mean vote
PPD	Predicted percentage dissatisfied [%]
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cold
-2	Cool
-3	Cold

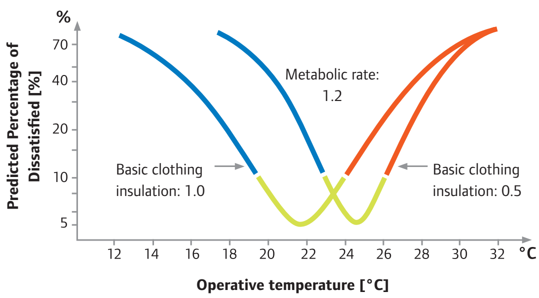
Seven-point thermal sensation scale

The PPD predics the number of thermally dissatisfied persons among a large group of people. The rest of the group will feel thermally neutral, slightly warm or slightly cool.

The table below shows the desired operative temperature range during summer and winter, taking into consideration normal clothing and activity level in order to achieve different comfort classes.

	Comfort requirements		Temperature range	
Class	PPD [%]	PMV [/]	Winter 1.0 clo 1.2 met [°C]	Summer 0.5 clo 1.2 met [°C]
A	< 6	- 0.2 < PMV < + 0.2	21-23	23.5-25.5
B	< 10	- 0.5 < PMV < + 0.5	20-24	23.0-26.0
C	< 15	- 0.7 < PMV < + 0.7	19-25	22.0-27.0

ISO 7730 basically recommends a target temperature of 22 °C in the winter, and 24.5 °C in the summer. The higher the deviation around these target temperatures, the higher the percentage of dissatisfied. The reason for the different target temperatures is because the two seasons apply different clothing conditions as can be seen in below figure:



Operative temperature for winter and summer clothing

Thermal comfort results

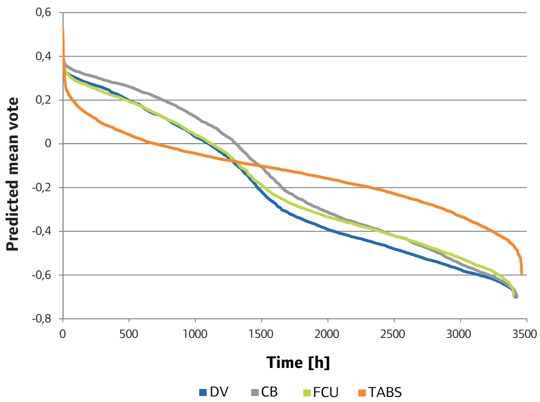
The thermal comfort comparison in the study shows that the TABS (case 1 and 2) are the closest to being thermally neutral among all tested cases. The PMV stays within class A in a south room under roof with TABS during 65% of occupied hours, whereas the same room equipped with chilled beam, fan coil and displacement ventilation only stays within class A between 26-31% of the occupied hours.

Airborne systems perform cooling primarily by convection. To achieve the same operative temperature without cooled radiating surfaces there was an increase in cooling energy needed. The higher cooling energy was by means of convection which impacted on the air volumes required. The higher air volumes increase the percentage of dissatisfaction to perceived comfort.

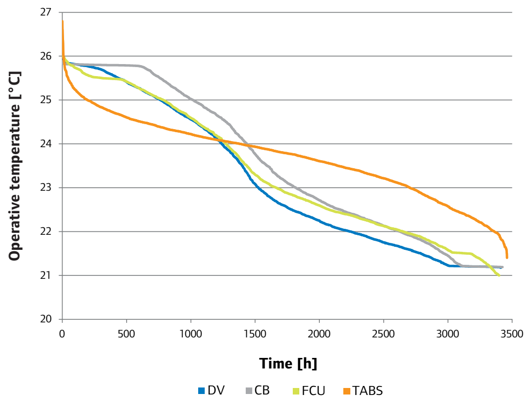
For the north corner office the TABS conditioned room remains in A-class during 54% of the occupied hours, while the same room conditioned with other HVAC schemes remains in class A within only 26-30% of time.

TABS provide lower temperature when in cooling and higher temperatures when heating compared to FCU, DV and CB. However, these temperatures are closer to thermal neutral sensation (ISO 7730). The FCU, DV and CB could also reach the same temperature levels like TABS, however, they would need to be upsized according, increasing investment cost, maintenance cost and energy usage.

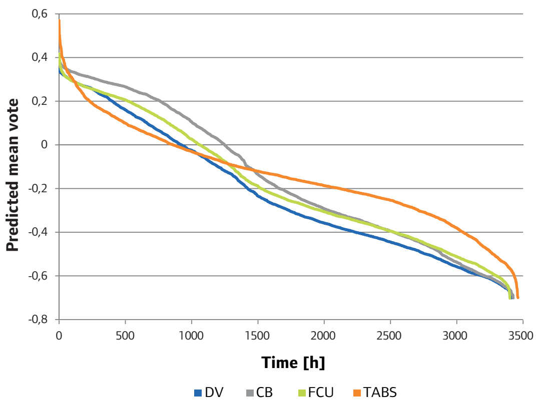
Thermal comfort PMV during occupied period South facade, office 407



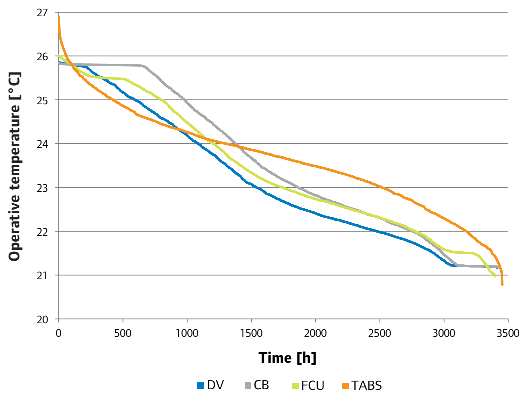
Operative temperature, duration curves for occupied period South facade, room 407



Thermal comfort PMV during occupied period North facade, office 306



Operative temperature, duration curves for occupied period North facade, office 306



Work productivity

Creating a comfortable environment in commercial structures is a critical design consideration. Comfortable employees are more productive and comfortable customers are more relaxed, contributing to the success of a business.

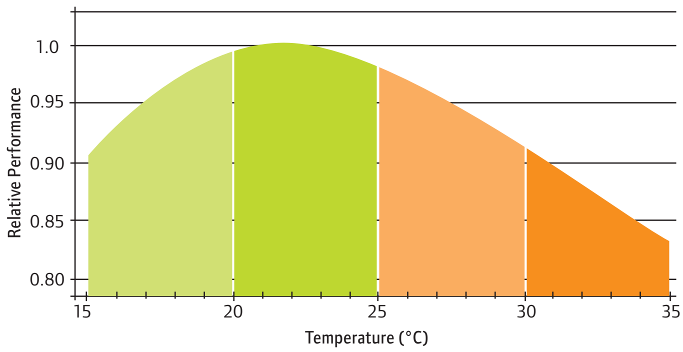
The indoor environment in office buildings directly affects both sick leave and work performance. The direct and indirect cost of a deteriorated office indoor climate can easily be as high as the costs for heating, cooling and ventilation.

The working environment is naturally affected by many factors including room temperature, air quality, ventilation, acoustics, daylight etc. Ventilation is always required to ensure an adequate indoor air quality, but in combination with a radiant heating and cooling system, the ventilation system can be optimized (sized smaller) to exclusively provide a good quality of the indoor air.

Reduced ventilation requirements means of course cost savings, as plant, fan and duct sizes are reduced, but furthermore it means that the ventilation air can be supplied to the rooms at higher temperatures resulting in better indoor environment. With reduced air flow volumes you also avoid cold draughts and circulation of dust and allergens, which are typical in traditional air conditioning systems. Radiant cooling is also silent – no noise from fans or blowers.

Embedded water based heating and cooling systems like TABS are named radiant systems because the major part of the energy exchange with the environment takes place via radiation. When correctly designed, the system maintains uniform temperatures over the different room surfaces – this means no radiation asymmetry and an ideal thermal environment!

Relative performance as a function of temperature



Source: Rehva guide book no 6., Seppänen et. al 2006

Low quality and deteriorated thermal comfort due to inappropriate conditioning systems means that initially saved investment costs will quickly be outweighed through illness-related absence and low staff productivity.

Conclusion

The present study provides life cycle cost (LCC) analysis of different HVAC systems installed in a 1000 m^2 office building located in London UK. The energy performance of the building has been simulated with a building simulation tool (IDA ICE) and the LCC evaluation has been done using the methodology of the EU Regulation No 244/2012 for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

The HVAC systems selected for the comparison were based on the typical specified systems for the UK market, and included traditional convective air conditioning; fan coils, displacement ventilation and chilled beams, which were compared to the performance of TABS.

The result has proved that choosing TABS from Uponor for the HVAC scheme will decrease the whole life cost for the building significantly compared to the alternative choices of HVAC schemes. The evaluation has found that TABS provides cost savings in the range from 12 to 31%.

In addition the results have shown that TABS improves the quality of indoor environment significantly for the benefit of personal health, productivity and reduced sick leave. By installing TABS the indoor environment, measured by the PMV index, will be in class A in up to 40% more of the occupied hours compared to alternative HVAC systems.

In conclusion, TABS has proven adaptable and cost effective for the UK conditions providing both cost reductions and improved indoor environment comapred to fan coils, displacement ventilation and chilled beams. Moreover the system is future proof as it works with any kind of energy source and facilitates the integration of renewable and free cooling sources.

Manchester Metropolitan University,
Manchester, UK

An efficient work environment is

- **Cost-effective**
  Minimised running costs, due to ability to use free and low-cost energy.

- **Employee friendly**
  An optimal working environment, with neither dust nor indoor draughts. A pleasant temperature motivates staff to perform at their best.

- **Reliable**
  A safe working environment with products that are proven in use. Being a partner with Uponor will bring benefits – reliably.

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