Effect Of The Hydraulic Piping Topology On Energy Demand And Comfort In Buildings With Tabs

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SUMMARY

A research project on the control and design of thermally activated building systems (TABS) has been started in May 2004. This paper presents one selected result after three years of work: Decision guidance and recommendations for HVAC design engineers regarding how to select an energy-efficient hydraulic piping topology for TABS.
The hydraulic piping system in TABS basically can be separated in a heating and cooling generation part, a distribution part and the consumer part which consists of several individually supplied zones. The heating and cooling demand of the zones is different from zone to zone and time-dependent. In this paper, two hydraulic piping topologies commonly used for TABS are analyzed in terms of energy consumption, resulting thermal comfort and understandability:
1) Injection circuits (in all zones) with one common return pipe for all zones
2) Injection circuits (in all zones) with separate return pipes for every zone
The paper presents a comparison between both topologies, using a realistic example, for which the piping topology has a considerable impact on the energy consumption. The example also shows the difference between the two piping topologies on the understandability and that it may have an impact on the comfort.
For the chosen realistic example, hydraulic piping topology 2) delivered better results.

KEYWORDS: HVAC design, hydraulic piping topology, thermally activated building systems (TABS), concrete core conditioning

INTRODUCTION

In this paper, two hydraulic piping topologies commonly used for TABS are analyzed in terms of energy consumption, resulting thermal comfort and understandability:
1) Injection circuits (in all zones) with one common return pipe for all zones (see Figure 1)
2) Injection circuits (in all zones) with separate return pipes for every zone (see Figure 9)
A common return pipe is generally selected for cost considerations.
Today, multiple flow pipes with various supply water temperature levels are often led to the TABS registers. The appropriate temperature levels can be selected (room or register assigned to a zone) with the help of a manual valve per zone during commissioning or changes in room use. In [1],[2] the corresponding implemented plants are described. The paper presents a comparison between the two topologies, using a realistic example, for which the choice of the piping topology has a considerable impact on the energy consumption. The example also shows the difference between the two piping topologies on the understandability and that it may have an impact on the comfort.

The dynamic whole-year simulation for this example will show that the topology with common zone return pipes (topology 1) has a considerable larger energy consumption than the other topology. The simulation will also indicate that the increased energy consumption comes from the fact that the circulated water must be cooled 360 days a year. The result is surprising at first glance and raises the following questions: Why? What is the behavior for a hydraulic topology with separate zone return (topology 2)?
We answer these questions and give the reasons in this paper by analyzing typical stationary load situations and whole-year simulations. We illustrate the different behavior of TABS with common and separate zone return as a matter of principle. Finally, we compare the energy demand of both investigated topologies.
The effect of the hydraulic piping topology on the energy demand and comfort with TABS was examined in the frame of a research project on which was reported for the first time in [3], [4].

1ST HYDRAULIC PIPING TOPOLOGY: COMMON ZONE RETURN

Figure 1 illustrates a typical hydraulic topology from a TABS, consisting of two zones with injection circuits with primary valves and a common zone return flow.

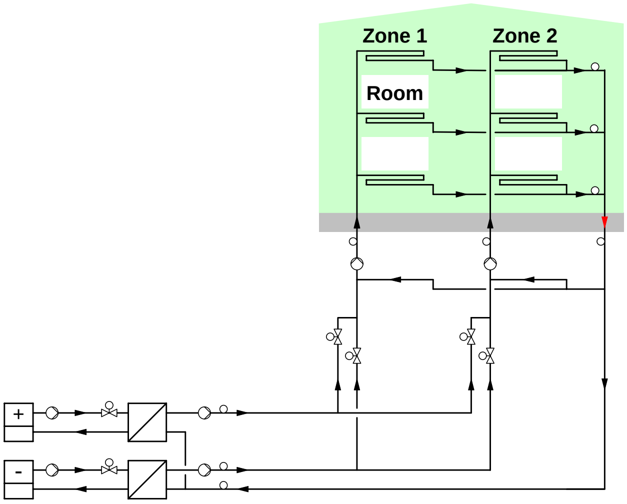

Figure 1: TABS hydraulic piping topology with common return pipe

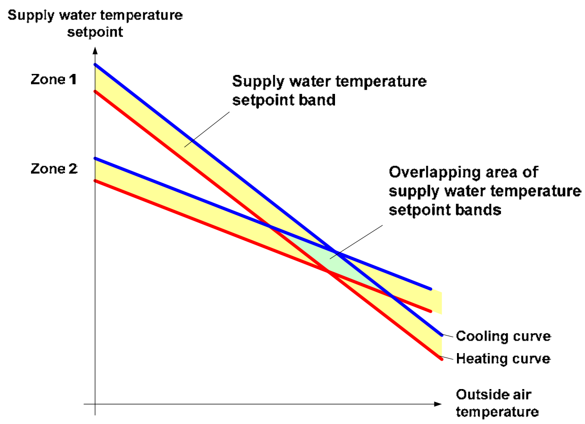

Figure 2: Supply water temperature setpoint bands for a two-zone plant, limited by heating and cooling curves

Supply water temperature setpoints are determined by using heating and cooling curves for each zone as outlined in Figure 2. In general, the curves or the resulting supply water temperature setpoint bands differ by their width and their slopes. Depending on the shape of these supply water temperature setpoint bands, there exists an outside air temperature range where the two supply water temperature setpoint bands overlap.
In [4], [5], [6], [7], an integrated design process for TABS and its control is given based on a so-called “unknown-but-bounded” approach. This approach allows – among other things – to determine adequate supply water setpoint bands.

Analysis of a stationary load situation

The following explains the behavior based on a typical stationary load situation in winter. Figure 3 and Figure 4 illustrate the supply and return water temperatures typically found during the winter: The supply water temperature for zone 1 must be at least 26°C and the temperature for zone 2 may be at most 23°C. The water cools by 0.5K in both zones, in other words heat is provided to the rooms.

At an equal volumetric water flow rate through zones 1 and 2, the common return water temperature corresponds to the mean of the zone return water temperatures, i.e. 24°C. The supply water temperature must be heated to 26°C for zone 1 and cooled to 23°C for zone 2 to achieve the desired supply water temperatures.

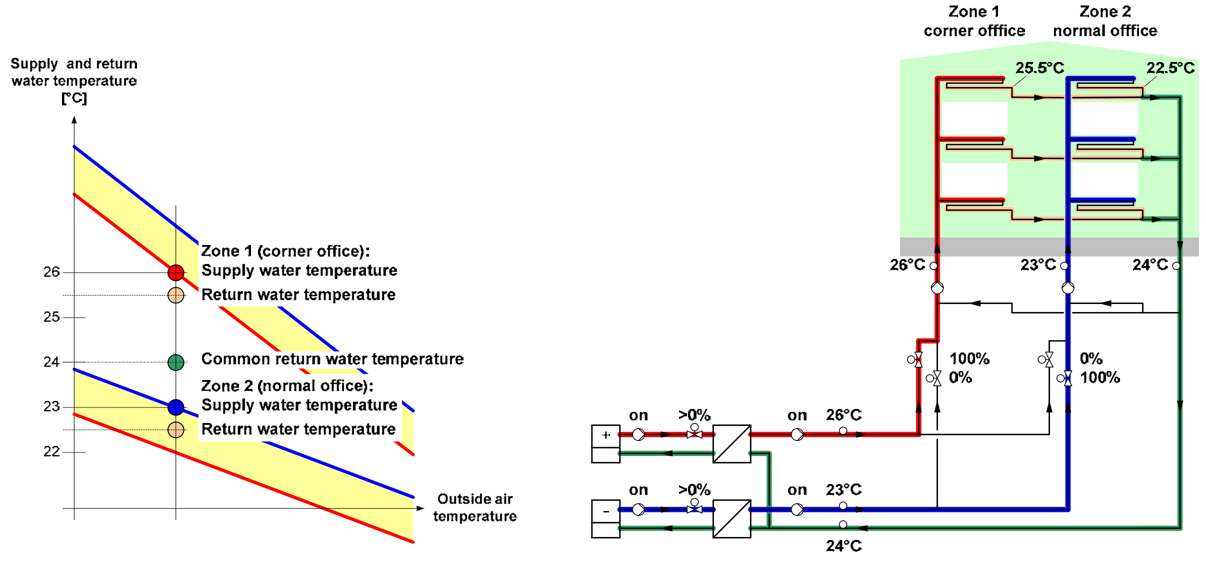

Figure 3 and 4: Temperature ratios and valve settings for common zone return during winter

The common return water temperature is higher than the supply water temperature setpoint for zone 2. The setpoint for zone 2 therefore cannot be achieved by admixing common return water to the supply.

- Although both zones have heat demands, in addition to heating also cooling is required to achieve the desired setpoints.
- If cold generation is blocked for this typical winter situation, the supply water temperature for zone 2 would be too warm and as a result, the room temperatures would exceed the room temperature cooling setpoint, i.e. thermal comfort cannot be achieved.

Analysis of a whole-year simulation

Two equal-sized offices, a corner and a normal office are assumed (see Table 1 and Table 2).

Table 1. data of the simulated zones (cf. [6])

		corner office	normal office
Space length, width, height		6 m x 6 m x 3 m	6 m x 6 m x 3 m
Façade	Orientation	West / South	West
	Area	36.0 m^2	18.0 m^2
	Overall U-Value	0.65 W/m^2K	0.65 W/m^2K
	Glazing fraction façade	42 %	42 %
Additional internal Wall (light)		36 m^2	36 m^2
Natural air change		0.2 h^{-1}	0.1 h^{-1}
Ventilation according to indoor air quality requirements (no cooling/heating by ventilation assumed)			

Table 2. data of the simulated TABS configuration, valid for both offices (cf. [6])

TABS covering fraction (floor area)	80 %
Thickness concrete slab	250 mm
Pipe spacing	200 mm
External/internal pipe diameter	20/15 mm
Specific supply water mass flow rate [a)]	15 kg/(h m^2)
Fictitious TABS thermal resistance (R_t) [a)]	0.08 (m^2 K)/W
Thermal resistance of flooring (carpet)	0.125 (m^2 K)/W

[a)] in terms of floor area covered by tabs

The corner office has twice the ratio of outside walls compared to the normal office. Construction, use and weather conditions correspond to a typical TABS building in the Zurich area (Switzerland). The same simulation set-up as described in [6] was used.

Refer to Figure 5 below, we assumed an outdoor temperature dependent comfort range according to SIA 382/1 [8]. During winter, the comfort range is between 21°C and 24.5°C, during summer between 22°C and 26.5°C. Pursuant to [6], [7], the supply water temperature setpoint band is influenced by the room temperature comfort range, among others: the wider the comfort range, the wider the supply water temperature setpoint band. As an example, refer to simulation results during the summer (Figure 7): the wide room comfort range during summer implies a wide supply water temperature setpoint band.

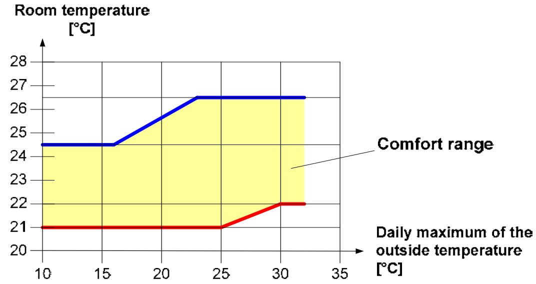

Figure 5: Room temperature comfort range according to Swiss national standard [8]

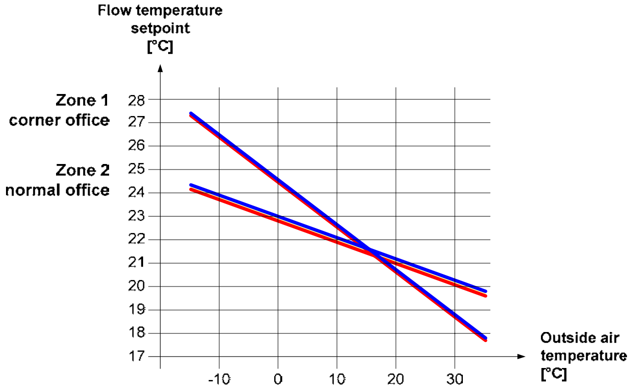

Figure 6: Heating and cooling curves for zone 1 (corner office) and zone 2 (normal office)

For the corner office and the normal office heating and cooling curves according to Figure 6 were determined. Due to the larger fraction of façade heating and cooling demand in corner offices is larger than in normal offices: This results in steeper heating and cooling curves than for normal offices. The heating and cooling curves were defined per the "unknown-but-bounded approach", which is described in [4], [5], [6], [7].
Since the heating and cooling curves are quite different for the two offices, separate zones have to be defined (see Figure 6).

The simulation results are recorded for a whole year, with days 180 to 270 representing summer. Simulation results are shown in Figure 7. Most of the time, the common zone return water temperature (green) is higher than the setpoint band for zone 2. As a result, cooling (magenta, negative value) is needed during most of the year to control the supply water temperature within the setpoint band.

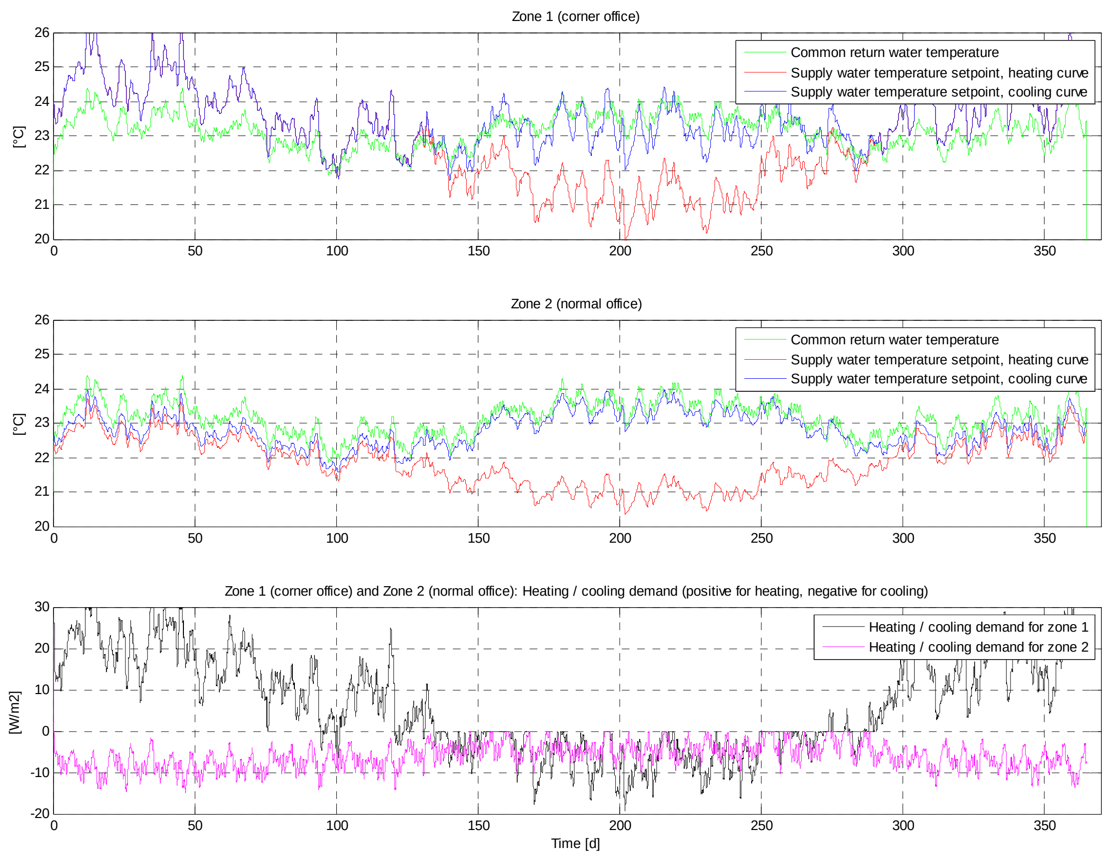

Figure 7: Whole-year simulation results for a TABS with common zone return

2ND HYDRAULIC PIPING TOPOLOGY: SEPARATE ZONE RETURNS

Analysis of a stationary load situation

Figures 8 and 9 illustrate supply and return water temperatures as typically found during the winter: The supply water temperature for zone 1 must be at least 26°C and the temperature for zone 2, 22°C. Water cools off by 0.5K in both zones, i.e. heat is provided to the rooms. The distribution supply water temperature is heated to the highest demanded supply water temperature (i.e. demand-controlled), or per zone 1 to 26°C. For zone 2, cooled off zone return water is mixed to achieve the setpoint (refer to Figure 9).

The setpoint for zone 2 can be achieved by mixing the distributed hot water with its own zone return water.

- Requires only heat to cover zone demand.
- Cold generation can be blocked for this typical winter situation.

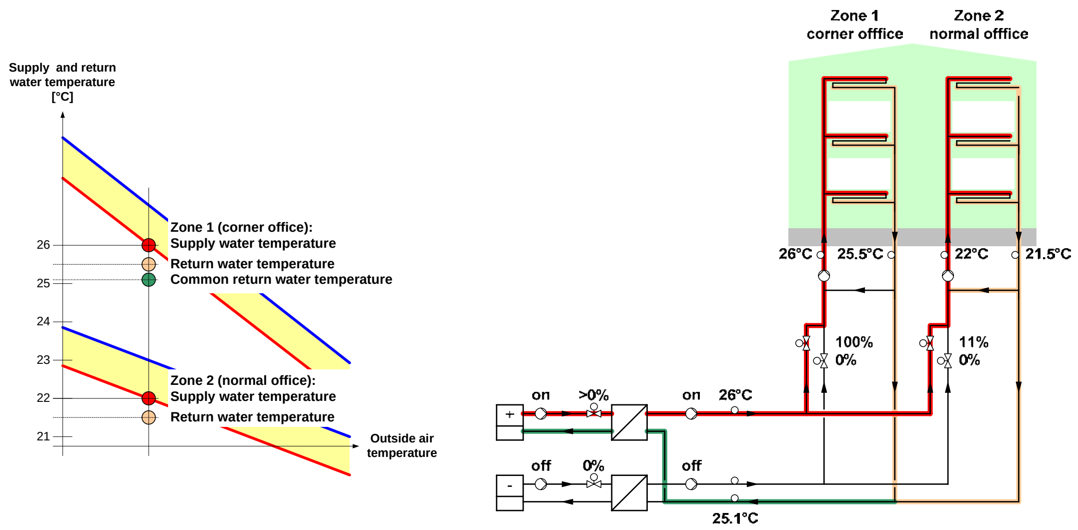

Figure 8 and 9: Temperature ratios and valve settings for separate zone returns during winter

Analysis of a whole-year simulation

In Figure 10, simulation results are presented when using the 2nd hydraulic piping topology. Here, the same simulation set-up was used as for the simulation with the 1st hydraulic piping topology (see Figure 7).

The simulation confirms the expectations: cooling is in winter only required during few days (magenta, positive value).

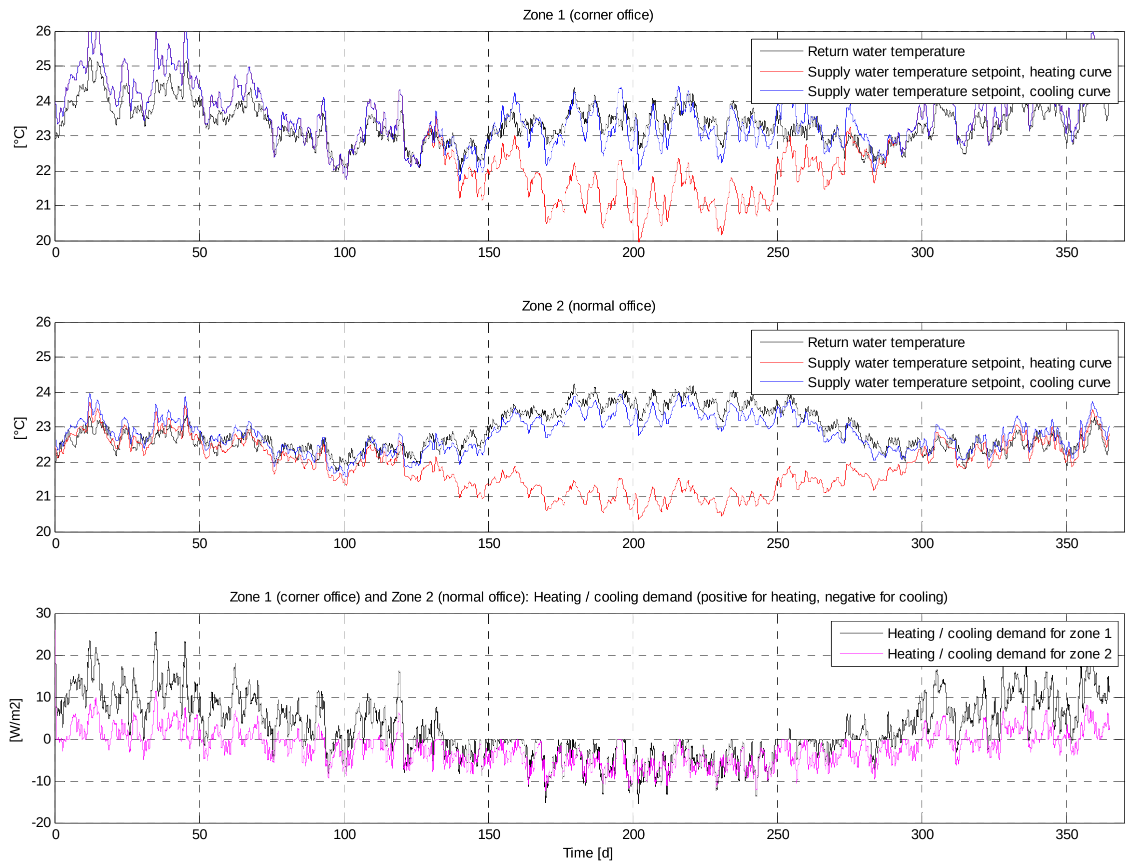

Figure 10: Whole-year simulation results for a TABS with separate zone returns

DISCUSSION

We found the following for hydraulic topologies with common zone return:
Decisive for current heating and cooling generation demand is not the TABS demand (what the room absorbs or is extracted from the room), but rather the actual position of the common zone return water temperature in relation to the supply water temperature setpoint bands of the zones:

1. If it lies between the zone supply water temperature setpoint bands pursuant to Figure 11 (cf. also Figure 2), cold water is required to achieve the zone supply water temperature setpoints below the common return water temperature and hot water above it. In other words, heating and cooling demand for the zones is not directly dependent on the TABS demand and therefore difficult to interpret. If, for example cold generation is incorrectly blocked for a typical winter situation (expected heat demand only), the supply water temperature setpoints below the common zone return water temperature can no longer be achieved. As a consequence, rooms in this zone may be too warm and the anticipated room comfort may no longer be maintained.
2. If it lies within the zone supply water temperature setpoint bands pursuant to Figure 11, a heat exchange may take place between the zones.

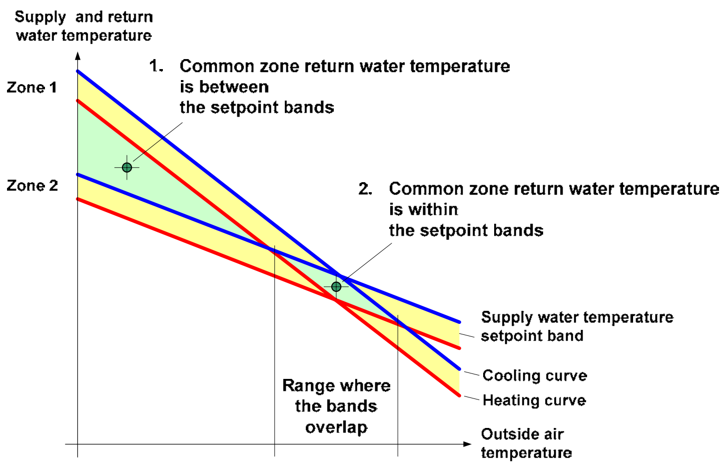

Figure 11: Common zone return water temperature between the supply water temperature setpoint bands (1.) and within the supply water temperature setpoint bands (2.)

The whole-year simulation resulted in the following for generation demand:

- 28 % less heat demand and 30% less cooling demand per year were required for the hydraulic piping topology with separate zone returns compared to the topology with a common zone return!

Depending on the shape of the supply water setpoint bands, an outside air temperature range results where the supply water setpoint bands overlap. The longer the real outside air temperature does stay outside of this outside air temperature range (over the year), the larger the potential energy savings by using a piping topology with separate zone return pipes compared to a piping topology with a common return pipe. If the potential is really exploited then depends on the load situations of the zones and the sizes (floor space) of the different zones (see [1]).
If the common zone return water temperature lies not within the zone supply water setpoint bands during a major part of time, we recommend separate zone return pipes based on current findings. This does result in higher investment costs, but lowers energy consumption,

increases understanding of operational behavior and improves room comfort. If separate zone return pips are installed and multiple flow pipes with various temperature levels are led to each register, (manual) valves for supply and return water have to be installed and they have to be switched so that supply and return are connected to the same zone.
As the present investigation is based on the specific assumptions concerning building characteristics, heat gain situation, proportion between normal and corner offices etc., the presented results strictly speaking are valid for the chosen example only. For situations with strongly deviating parameters results and conclusions may be different.
The presented results in this paper can be transferred to other systems than TABS and also to systems with different heat and cold transfer medium like air conditioning systems. Whether or not different hydraulic topologies provide additional benefits is the subject of further examinations for this research project.

ACKNOWLEDGEMENT

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