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Performance study of concrete core activation for office buildings in a hot-humid climate

Pouria Fatalian[#], Kliment Kostadinov-Pramatarski[#], Jelle Laverge[#1], Wim Boydens[#*2]

[#]*Building physics, construction and services research group, Ghent University*
J. Plateaustraat 22, 9000 Gent, Belgium

[1]jelle.laverge@ugent.be

[*]*Boydens Engineering*
Autobaan 13, 8210 Loppem, Belgium

[2]wimb@boydens.be

Abstract

The objective of this paper is to analyse what the possible benefits and risks could be when adding Concrete Core Activation (CCA) to classical air-conditioned buildings in a 'hot and humid' climate. The characteristics of hot humid zones are completely different to those of temperate climates where many years of trial and error with different air based or radiant HVAC systems have led to near optimal operation.

The presented work is a simulation study comparing classical HVAC concepts to CCA assisted concepts in a reference building. The studied building is located in Singapore. With its low latitude of 1°17'N causing high solar radiation and the proximity of large natural water surfaces, Singapore has a climate with high humidity levels and hot daily mean temperatures.

The use of CCA changes the complete performance of the system and the energy consumption of the building in a positive way. When CCA is added energy consumption, operating costs, ACRs and degree-days are reduced. Even improved AC models can't reach the same results as a worsened A+C model.

When changing parameters the models with and without CCA reacted in a different way. The changes in the performance of A+C models were much less pronounced than the reaction of AC models. The possibility to improve or worsen a model is much greater for AC models than for A+C models.

Keywords – TABS, CCA, hot and humid, simulation

1. Introduction

Concrete core activation (CCA), a form of thermally activated building systems (TABS) where hydronic circuits are included in the concrete structure of a building, is a high surface area heating or cooling system. Due to this, the temperature difference between the water in the system and the indoor environment can be kept very small and the heat or cold can be produced at very high efficiency. For this reason, CCA has become very popular in the moderate climate region of Europe.

Large parts of the world population, however, lives in a hot and humid climate region, such as South-East Asia, central America or central Afrika, as is shown in figure 1. In these regions, All-air systems dominate the HVAC market. In this paper, we

investigate the potential of CCA to provide adequate thermal comfort at higher efficiencies under such climate conditions using dynamic simulations of a medium sized office building and an accompanying sensitivity analysis.
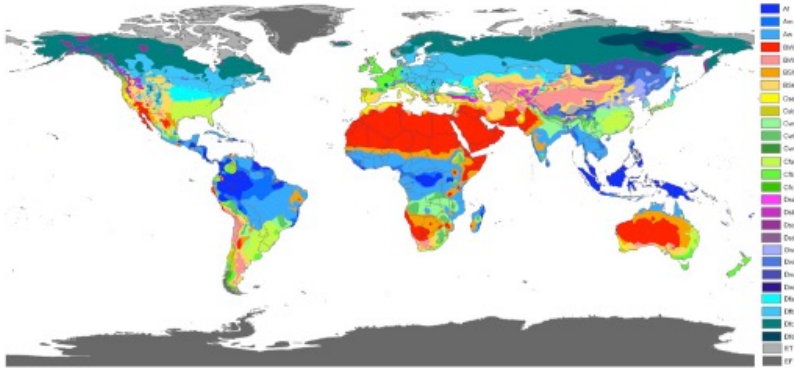

Fig. 1 world climate classification according to Köppen [1]

2.   Methods

The building considered in this paper is an existing freestanding office building built in Brugge, Belgium. It consists of 6 levels: a collective ground floor and rooftop level and 4 office levels in between. The office levels have a net surface of around 700m^2 and consist of different rooms for different types of business activities. All levels have a similar structure with collective meeting rooms in an L-shape in the southern and western part while open plan offices are organised at the northern and eastern façades. The center of every level consists of small bureaus, storage rooms, toilets and horizontal or vertical circulation. There is also a large staircase in the south-western corner of the building that connects all levels.

Since the office levels have a similar construction and distribution of functions, for calculation and parameter analysis only office level 3 will be simulated. A typical floorplan of the building is shown in figure 2. The building was modeled in TRNSYS with both an all-air and a CCA + VAV system. The main modeling assumptions are summarized in figure 3 and the variations used in the sensitivity analysis are listed in figure 4. Further details about the modeling can be found in [2] and [3].
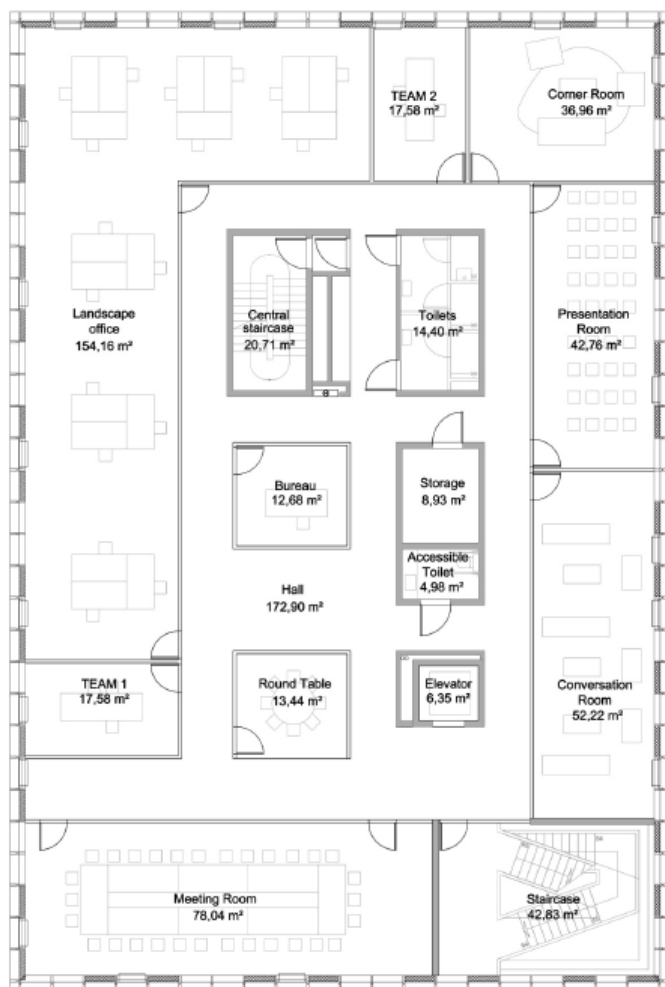
Fig. 2 Third floor of the reference building

Building Physics (Tref25)		
	Orientation	standard with landscape office in north and presentation room in south
Façade characteristics	Amount of glass	40% facade surface
	Glass type	u-value: 1.1 g-value: 0.609
	Insulation thickness:	10 cm Rockwool
	Infiltration Flow through surface	Infiltration class 3 with Infiltration Flow 0.15 m³/hr/m²
Light & shadow	Minimum luminous intensity outdoors	30 000 lux on a horizontal surface
	Period of sunlight intensity on horizontal surface	Solar blind goes down after 30 min of 30 000 lux on a horizontal surface
	shadings factor	0.9 for variable solar blinds
	Operation period of variable Solar Blinds	only during working hours
	Permanent Solar shading (Wingwall)	the wings are 0.3 m lang
	Permanent Solar shading (Overhang)	0 m
Open windows	Open	T room > 35
	Close	T room < 24
	Timing open windows	only during working hours
Comfort	upper limit	23.45+0.11*T_ref upper limit comfort PMV model
	lower limit	19.55+0.11*T_ref lower limit comfort model PMV
AC (Tref25)		
Controlling	Period of ventilation	08:00-19:00 only on weekdays
	Solar collector	8 - 20 hr
	Cold storage tank	ΔT > 4°C on & ΔT < 1°C off
Temperature	Supply air	16°C
	Chiller regime	7-12 °C
	Desired room temperature	25°C
	Cooling tower regime	34.5 - 29.5 °C
Ventilation rate	Minimum ventilation rate	hygienic ventilation
	Maximum ventilation rate	20 x volume of the room
	Minimum ventilation rate in meeting rooms	2 only for meeting rooms when they are not in use
	IDA classification	36 m³/ hr per person
Solar collector	Area	50m²
	Storage tank volume	2m³
	Fluid Flow rate	1200 kg/hr

Fig. 3 Modeling parameters for the basic model

Parameter	Base model value	Simulated values
Building rotation	0°	90°
Insulation thickness	10cm	5 and 20cm
Glass fraction	40%	20%, 60% and 80%
Glass type	g=0,61	0,40
Solar shading factor	0,9	0,5 and 0,3
Solar blinds reaction time	0,5h	1h and 2h
Terrace depth	0m	1m and 3m
Surface permeability	3 m^3/h/m^2	1, 6 and 12 m^3/h/m^2

Fig. 4 Variations in the sensitivity analysis

In office buildings the HVAC system has the function to change the room's indoor climate to comfortable conditions. Determining the condition that the average employee will regard as comfortable isn't as easy as it sounds. Many studies regarding human indoor comfort have determined many formulas but they all can be grouped in 2 categories: static and adaptive comfort models.

The static and most commonly used comfort model is Fanger's PMV-model [5-7]. It tries to predict which percentage of the people will be (dis)satisfied with the indoor climate and is based upon activity levels, clothing, radiant and ambient temperatures, humidity and air velocity. PMV's major problem is not taking the outdoor temperatures into account.

Adaptive comfort models [8-15] attempt to solve this but in most cases create models that have to be calibrated according to the tested area and climate. Nevertheless Nicole and Humphreys' and De Dear and Brager's models were adopted in American standard ASHRAE55 and in European standard EN14541 besides Fanger's PMV model [16-19].

Regarding HVAC an office building in a hot and humid climate will need yearlong cooling and dehumifying in order to obtain comfort according to any of the discussed comfort models. The different systems were studied in within the bounderies of the PMV and the Nicole and Humphreys comfort model.

3. Results

For each of the simulations made, the yearly energy use for the operation of the chillers, fans, circulation pumps and cooling tower pumps was calculated. The distribution of these energy uses for the base case scenario is listed in figure
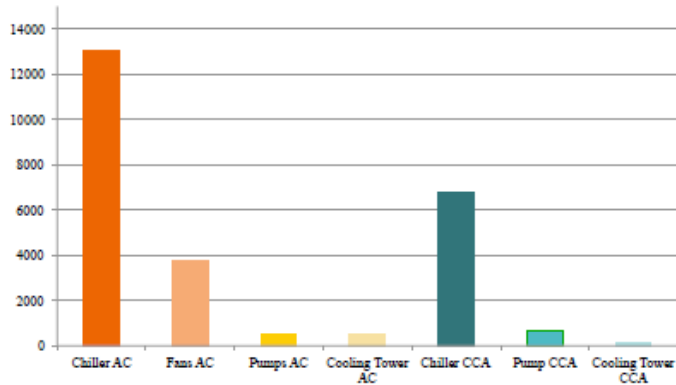

Fig. 5 Energy used by chillers, fans and pumps over the course of 1 year in the base case scenario, in kWh

Applying a 'one at the time' sensitivity analysis, the robustness of the performance of the system is investigated and compared to that of a traditional all-air system.
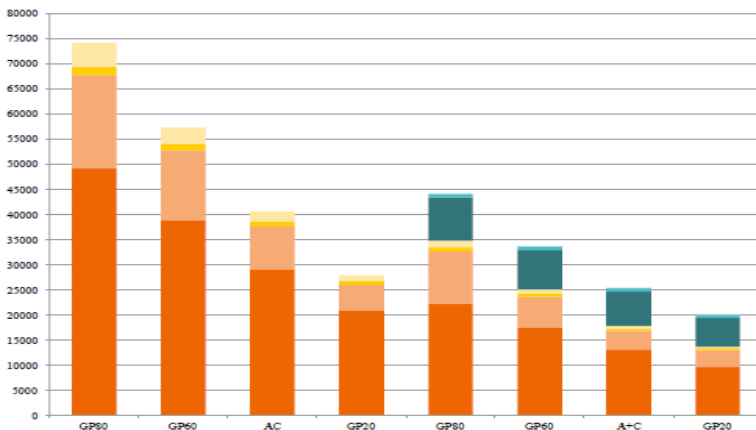

Fig. 6 Energy used by chillers, fans and pumps over the course of 1 year for the all air and the CCA assisted system for 80-60-40-20 % of glazing

In figure 6, for example, the energy use of the all-air system is compared to that of the CCA assisted system for different amounts of glazing in the building envelope, ranging from 80% to 20%. In each of the studied situations, the CCA assisted systems saves a substantial amount of energy, and these energy savings are relatively more important the higher the original cooling load is.

Additionally, the CCA assisted system also achieved more acceptable indoor temperatures and a reduced air change rate, as is shown in figure 7.
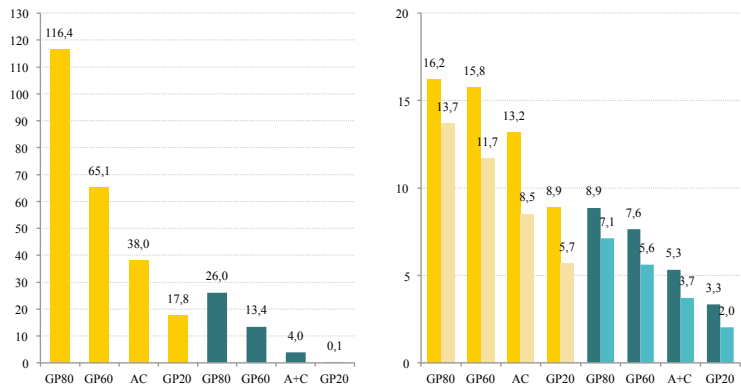

Fig. 7 Degree-days per year exceeding the comfort theashold and average air change rate for the all air and the CCA assisted system for 80-60-40-20 % of glazing

Additionally, the application of a CCA system in a naturally ventilated building was studied. Naturally ventilated buildings are typically the lower end of the market, and the thermal comfort is much worse than that of all air systems since they do not have active cooling. Adding CCA improves comfort at a minimal energy cost (figure 8).
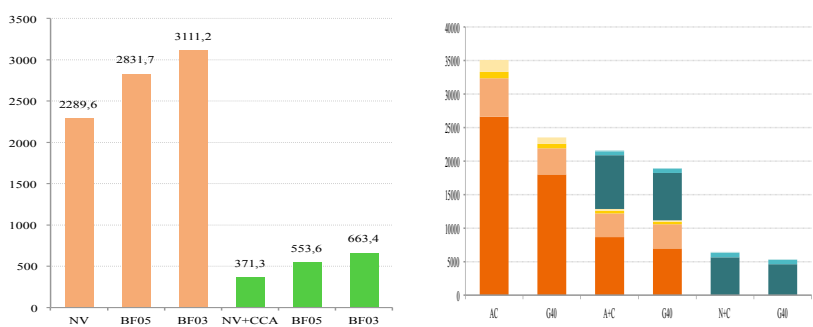

Fig. 8 Degree-days per year exceeding the threshold and energy use in naturally ventilated building

4. Conclusions

The objective of this paper was to analyse what the possible benefits and risks could be when adding Concrete Core Activation to classical air-conditioned buildings in a 'hot and humid' climate. The characteristics
of hot humid zones are completely different to those of temperate climates where many years of trial and error with different air based or radiant HVAC systems have led to near optimal operation.
The studied building is located in Singapore. With its low latitude of 1°17'N causing high solar radiation and the proximity of large natural water
surfaces, Singapore has a climate with high humidity levels and hot daily mean temperatures. The monotonous climate without pronounced seasons can be classified as 'Tropical' or Aw according to Köppen's climate classification.
In order to assess the risks and benefits of CCA, two types of air based models were studied: naturally ventilated and air conditioned building, both with and without the addition of CCA. After extensive parameter study several conclusions were made for the mechanically cooled buildings:

- The use of CCA changes the complete performance of the system and the energy consumption of the building in a positive way. When CCA is added energy consumption, operating costs, ACRs and degree-days are reduced.
- Even improved AC models can't reach the same results as a worsened A+C model.
- When changing parameters the models with and without CCA reacted in a different way. The changes in the performance of A+C models were much less pronounced than the reaction of AC models. The possibility to improve or worsen a model is much greater for AC models than for A+C models.
- The main source of heat load on the building is the solar radiation. Even when partly removed the system's performance changed profoundly. The addition of terraces, that function as fixed solar shading, and installment of glass with a low solar transmission will result in a vast improvement of the building's energy consumption and indoor comfort.
- The A+C models have much lower degree-days. As the model's reference temperature is set to be 1°C below the upper limit of the comfort models, this means that the addition of CCA will result in a system that can better counteract internal or external changes that increase the cooling load. CCA is much more dominant than AC: high ACRs don't correspond to fewer degree-days, nor do they correspond to high energy consumption.
- In moderate climates nocturnal temperatures will be generally lower than the inside comfort temperatures.

Though in tropical climates the nighttime temperatures will sometimes be inside or just below lower comfort temperatures. This changes the function of some typically important elements in moderate climates like thermal insulation, infiltration or nighttime natural ventilation. When defining a supply water temperature for CCA it is important that this temperature is above the dewpoint of the inside air to avoid condensation, but when it's also above the average nighttime temperature it will benefit from transmission losses to the outside environment.

Naturally ventilated buildings function in a completely different manner as regards to composition, façade design, air supply and exhaust locations, etc. The results for these NV buildings are not even in the range to the results of the mechanically cooled buildings. The same building related conclusions that are valid for mechanically cooled buildings are also valid for NV buildings.

An important problem with cooling buildings with natural ventilation is that every improvement of the thermal comfort by (for example the addition of CCA) might have very negative consequences regarding mold growth.

There has to be specific attention when designing rooms that could be cool but at the same time supplied by untreated air.

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