RELATIVE HUMIDITY ANALYSIS, RETROFITTING THE SINT-PIETERSCHURCH IN GHENT

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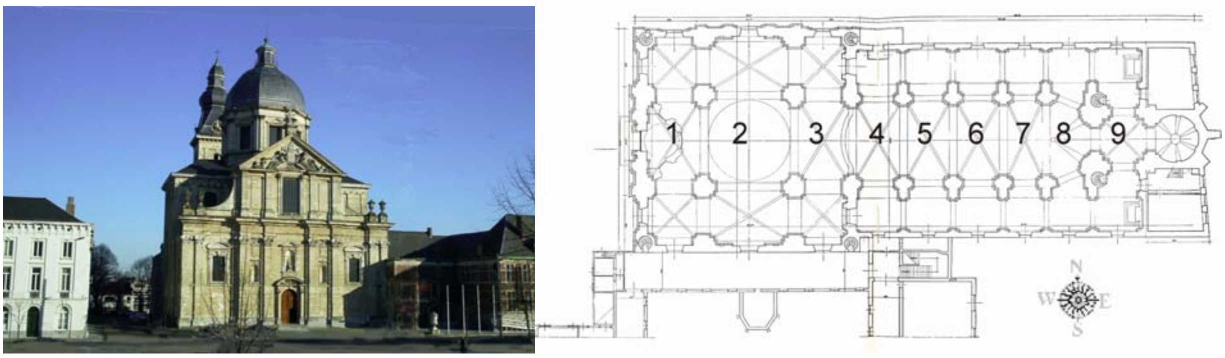
ABSTRACT

The Sint-Pieterschurch in the city of Ghent is ne of the larger churches of the city. It was build in the 17th century. The city council wants to use the church not only for it's religious functions, but also for cultural activities as concerts and exhibitions. To be able to do this the thermal comfort of the visitors has to be guaranteed. At this moment the church has no central heating system. Gas heaters are used during services. Installing a central heating system will influence the humidity and moisture behaviour of the church. As the church contains several important works of art as well as a monumental organ, it is of great importance to analyse the air humidity behaviour of the church. Rapid changes in moisture content of the valuable objects can cause great damage to them.
In this paper CFD (Computational Fluid Dynamics) using FLUENT is used to evaluate the effect of heating on air flow, temperature distribution and relative humidity variation inside the church. Measurements were done inside the church, with special attention being paid to the area around the organ. This way a suitable heating system is selected and an optimum distribution of air inlet can be determined.

KEYWORDS

CFD, heating, relative humidity

THE ST. PIETER'S CHURCH, GHENT, BELGIUM



(a) (b)

Figure 1: Front view (a) and floor plan of the St. Pieter's Church

About 630 AD Saint Amand founded the Sint-Pieters abbey at the highest point of Ghent. The abbey became very famous during the Middle Ages, but in 1566 AD the church and the abbey were badly damaged during the iconoclastic fury. Only in 1629 AD the first stone of the current baroque church was laid (Figure 1 (a)). Today, the church is used for services and

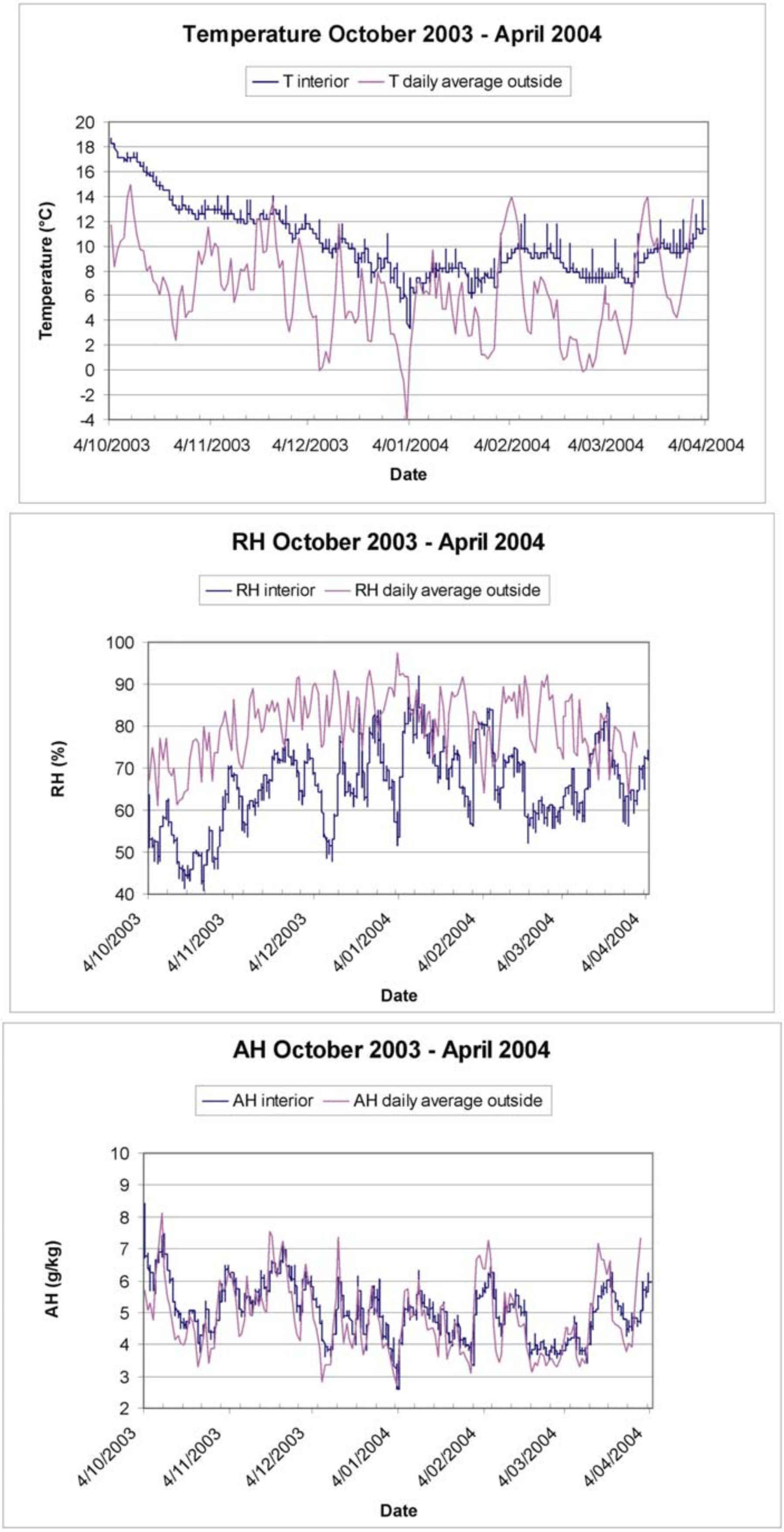


Figure 2: Global results of the measurements

cultural events and the abbey has become a tourist attraction. The St. Pieter's Church is decorated with many paintings and sculptures of famous artists. The monumental organ, built by Van Peteghem, 1849 AD, is an unique work of art (Van Driessche, 1980).

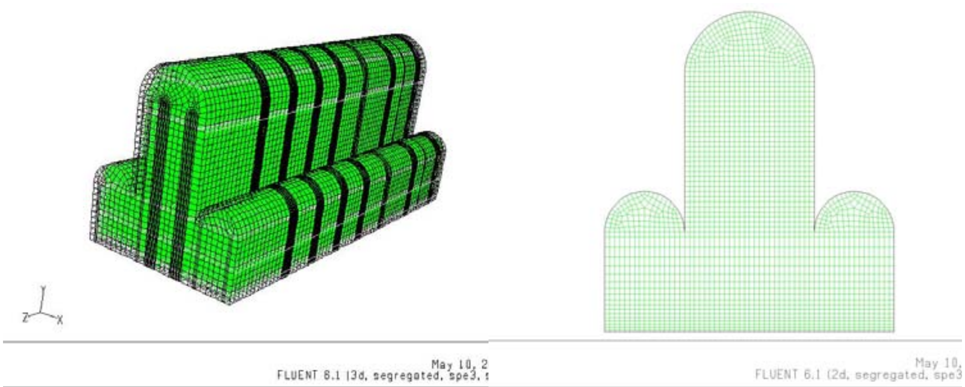
The floor plan is given in Figure 1 (b). The church has a total length of 88 m and a maximal width of 30 m. The internal height is about 17 m in the side aisles, about 32 m in the nave and about 52 m in the dome. With its 74 m, the steeple is the highest point of Ghent. The church walls are made of limestone and masonry and have an average thickness of about 1 m.
At the moment, there is no central heating system in the church. Gas burners fuelled by propane are used to heat the church during wintertime services and cultural events. The installation of a heating system is planned.

Heating causes the inside air relative humidity to drop. This can bring on problems concerning the conservation of historical works of art (Schellen, 2002). Dryer air will reduce the moisture content of for example wood. This may cause the works of art and the monumental organ to suffer from cracks due to shrinking. On the other hand, too humid conditions may cause problems of mould (RH > 80%). In this paper an analysis is made of the current behaviour of the church concerning air humidity, ventilation and moisture storage. This was done by an intensive measurement campaign. Using the obtained data, a CFD-model was built in order to analyse the impact of two heating system in the church : floor heating and convector heating.

MEASUREMENT CAMPAIGN

In October 2003 measurements were started in the church. Temperature and relative humidity (RH) loggers were installed at several points in the building. The global results are given in Figure 2. The temperature decreases from 18 °C in the beginning of October 2003 to 5 °C in January 2004. From March 2004 on the temperature increases. The relative humidity varies between 40 and 90 % and the absolute humidity (AH) varies between 3 and 7 gr/ kgair. There is a time delay between the changes in the indoor and outside climate.

Measurements confirm that the church has a stable climate. The temperature and humidity differences over the church volume are small. The current heating method only influences the indoor church climate locally and for a short time period. A few hours after turning down heaters, their influence disappears. The church can be represented as a large, homogeneous volume, with a low moisture content. Still, the existing situation with high relative humidity in winter is not without risk for mould initiation. With a thermographic camera the wall temperature was measured. Homogeneous surface temperatures were observed.



(a) (b)

Figure 3: 3D calculation model (a) and 2D calculation model (b)

MODELLING TEMPERATURE AND HUMIDITY DISTRIBUTION IN FLUENT

Calculation grid

To see the temperature and humidity distribution over the church a three dimensional calculation model was created. Some effects can be studied in two dimensions, which significantly reduces calculation time. Figure 3 shows the 3D and 2D grid.

Heat losses

Measurements in the church indicated the restricted heat losses by leakage. The main part is caused by heat transport through the walls. It is not easy to determine little losses through cracks and windows and their influence in this model is neglected. Therefore the walls are set as fixed temperature surfaces as boundary condition in FLUENT. The wall temperature is depending on the outside temperature. The estimated U-coefficient of the wall is 0.98 W/m².K.

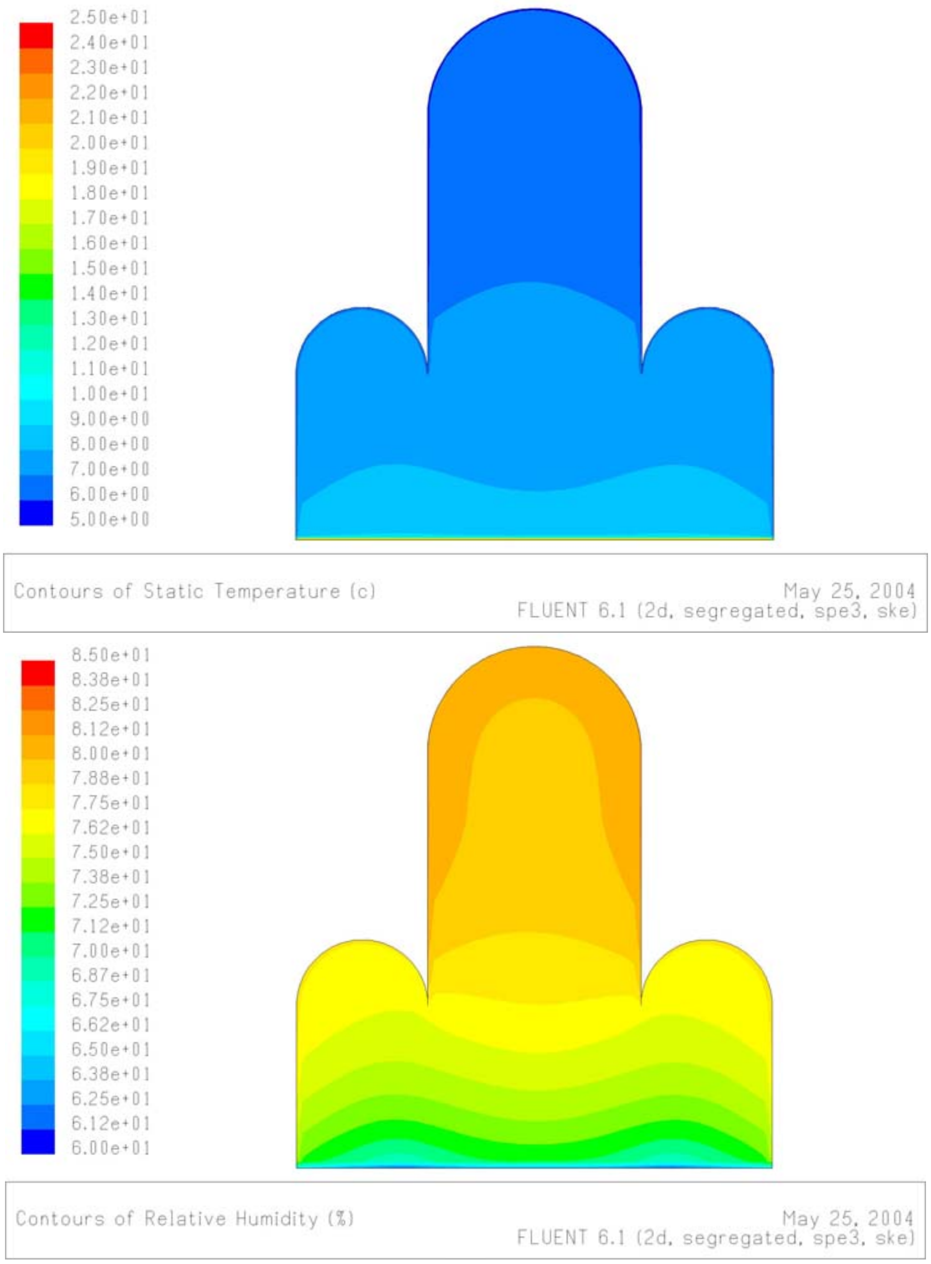


Figure 4: Floor heating simulation

Floor Heating

Modelling floor heating in FLUENT can preliminary be done in a 2D model. The whole floor is implemented as a fixed temperature wall boundary condition. FLUENT solves the energy equation by balancing the incoming and outgoing heat flows, taking buoyancy into account. Calculations were made for a typical winter day assuming an outdoor temperature of 1 °C. Floor temperature was set to 25 °C. The temperature inside the church obtained out of the simulation is on average 7 °C (Figure 4). This is not sufficient. It is thus not possible to heat the St. Pieter's Church to a sufficient level without reaching an excessively high floor temperature. The height of the church is too big in comparison to the (floor)surface available for heating. With a moisture content of 4,87 gr /kg air the relative humidity varies from 60 to 85 %.

It is clear that for detailed simulations, a more precise determination of the wall characteristics is necessary. Although this model gives a general view on the heat loss, suitable for this church.

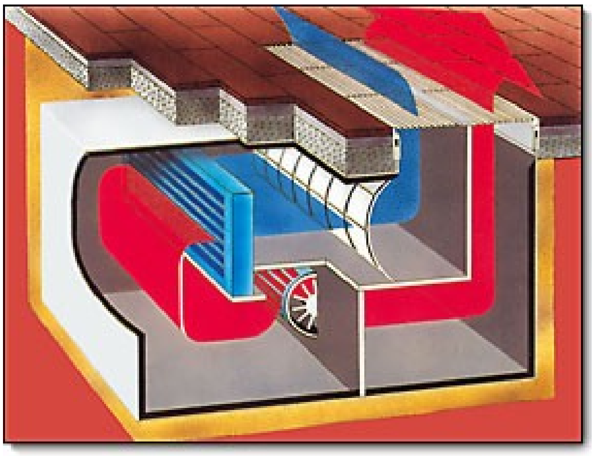


Figure 5: Mahr convector well

Convector well Heating

A convector well heating system is planned for the retrofit. Hot water will be distributed to convector wells spread around the church, where a heat exchanger will create hot air. Through the grille on floor level, cold air will be heated and the hot air will be expelled (Figure 5), as described in (Mahr 2004). This decentralised heating system can produce a maximal power of 35 kW per convector well. To simulate the effect of this heating system in FLUENT, the inlet of a convector well is defined as a velocity inlet, with a velocity magnitude of 0,4 m/s and an incoming temperature of 25 °C. The outlet is defined as a pressure outlet. The heat losses through the walls are defined as described above.

In Figure 6 the balanced situation is shown in the 3D model for a simulation with 18 convector wells with a heat input of about 5 kW each. The convector wells create a very homogenous temperature distribution and the church is heated till 11 °C. The relative humidity varies between 25 and 63 %. Despite the approximations, it is clear that sufficient heating causes low local relative humidity.

CONCLUSION

At the moment the Sint-Pieters church in Ghent has a fairly stable indoor climate, without any dry out or condensation problem. Installing a good heating system in the St. Pieter's Church is not obvious. Two possibilities are evaluated in FLUENT. In view of the building characteristics of the church, floor heating is inadequate. Convection wells can deliver enough heat, but the evolution in the relative humidity has to be taken into account.

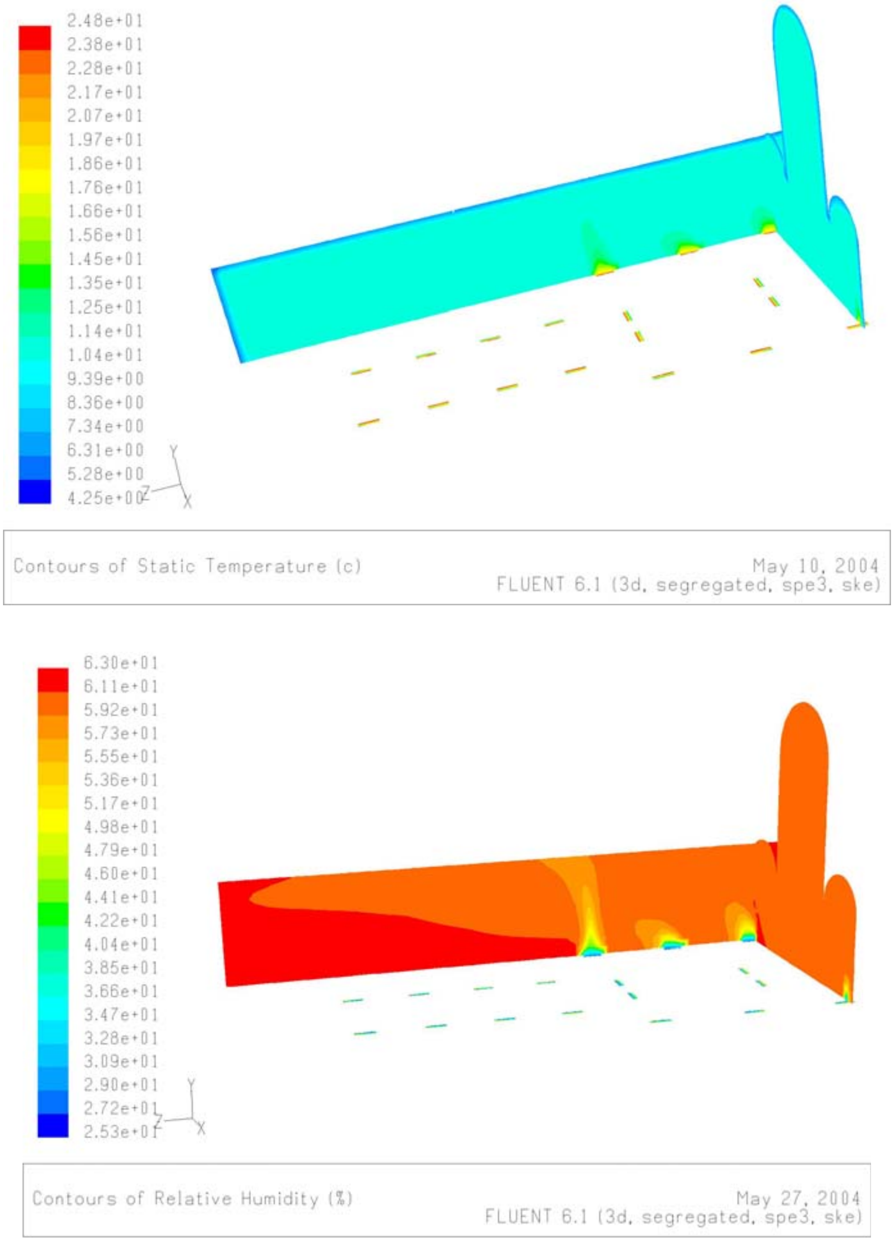


Figure 6: Convector well heating simulation

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