TEMPERATURE AND VELOCITY DISTRIBUTIONS IN A CHURCH WITH FLOOR HEATING IN VARIOUS SEASONS

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ABSTRACT
In this paper the experiences carried out in a large church of Bologna equipped with a floor radiant panels heating plant are presented. High intensity air flows were measured not compatible with thermal comfort. Experimental data will form the basis for understanding and controlling thermal instabilities in very high halls.

KEYWORDS
Natural convection, Thermal comfort, Full scale experiments, Public buildings

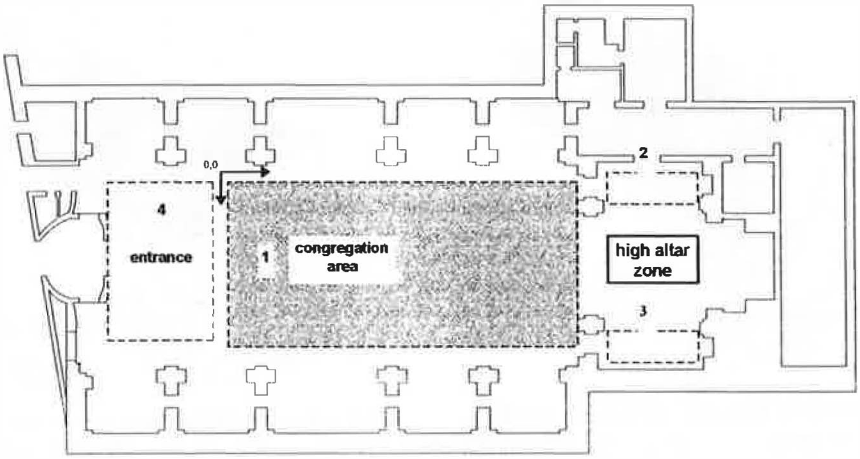

Fig.1 - Planimetry of the Church; 1, 2, 3 and 4 are representative of heated zones

INTRODUCTION

Buildings used in industry are nearly always characterised by volumes and dimensions of considerable size, mainly in height, which favour the occurrence of thermal instability phenomena independently of the air-conditioning system or HVAC plants used. Indeed, the presence of temperature differences between the building curtain surfaces (floor, walls, ceilings, windows, etc.) and those relating to any internal thermal sources (lighting equipment and mechanical and electrical components) may create natural convection phenomena of great intensity.

This causes objective difficulties in controlling thermal comfort, indoor air quality and the dispersal of polluting substances.

An engineering solution commonly utilised is the installation of floor radiant panels heating systems.

Several are typical of that techniques advantages :

- a lower vertical air stratification compared with classic HVAC systems;
- reduced energy consumption on account of the low temperature of the heating fluid (35-45°C);
- absence of the obstacles due to the presence of HVAC terminal components.

	12,5				4,7				12,5
	16,7				8,0				16,4
	11,7				17,3				14,4
	13,1								14,2
	17,7				11,9				15,5
1	11,9	n.r.	19,5	n.r.	22,6	n.r.	25,1	n.r.	11,0
4	15,8	n.r.	12,5	n.r.	19,2	n.r.	18,9	n.r.	15,7
7	16,7	n.r.	18,8	n.r.	24,9	n.r.	20,5	n.r.	18,5
10	10,0	n.r.	14,4	n.r.	24,7	n.r.	16,5	n.r.	12,1
13	13,0	n.r.	17,5	n.r.	18,4	n.r.	13,9	n.r.	12,7
	11,9		13,7		22,5		17,1		14,5
	12,4		13,9		18,6		17,8		17,5
	14,0		15,0		17,1		19,8		12,3

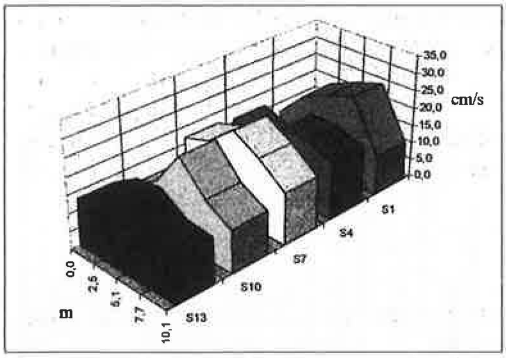

Fig. 10 - Mean velocity values (cm/s) - h=0.15 m - april 96

	14,1				4,5				10,6
	9,5				6,2				9,5
	11,6				15,3				10,6
	11,3								10,5
	15,2				20,8				14,5
S1	16,1	n.r.	17,5	n.r.	15,5	n.r.	17,7	n.r.	13,3
S4	6,8	n.r.	20,3	n.r.	18,0	n.r.	19,2	n.r.	16,1
S7	10,4	n.r.	16,4	n.r.	19,0	n.r.	17,0	n.r.	18,1
S10	10,2	n.r.	15,6	n.r.	22,7	n.r.	13,5	n.r.	12,0
S13	8,1	n.r.	11,8	n.r.	18,3	n.r.	13,9	n.r.	10,0
	13,3		13,8		10,0		8,2		8,0
	16,0		11,6		14,7		10,2		11,6
	13,9		13,5		9,5		12,0		11,1

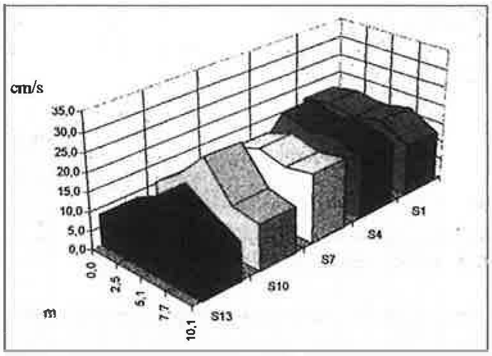

Fig. 12 - Mean velocity values (cm/s) - h=1,25 m - april 96

	22,5				23,0				22,5
	22,2				22,3				22,2
	22,4				22,0				22,8
	22,7								22,5
	22,5				22,2				22,5
S1	21,8	n.r.	22,2	n.r.	21,4	n.r.	21,3	n.r.	22,6
S4	22,1	n.r.	22,8	n.r.	21,6	n.r.	22,5	n.r.	22,2
S7	21,7	n.r.	22,3	n.r.	22,0	n.r.	22,6	n.r.	21,6
S10	22,5	n.r.	22,5	n.r.	21,9	n.r.	22,8	n.r.	21,9
S13	21,5	n.r.	22,2	n.r.	22,2	n.r.	22,1	n.r.	21,6
	22,2		22,1		21,6		21,6		21,0
	22,5		22,3		22,2		22,1		22,0
	22,5		22,5		22,1		21,6		21,2

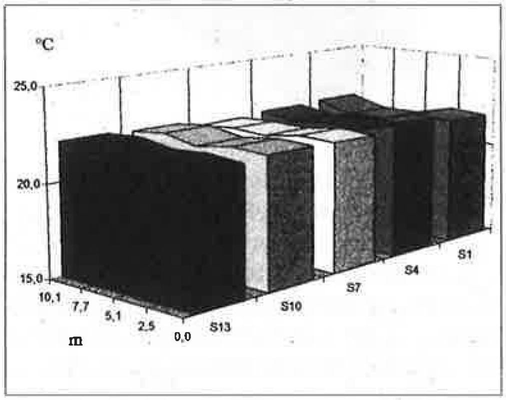

Fig. 11 - Mean temperature values (°C) - h=0.15 m - april 96

	22,6				23,2				22,8
	22,7				22,8				22,4
	22,7				22,2				22,5
	22,6								22,5
	22,5				22,4				22,6
S1	21,8	n.r.	21,9	n.r.	21,4	n.r.	21,4	n.r.	22,0
S4	22,2	n.r.	21,7	n.r.	21,8	n.r.	21,6	n.r.	21,9
S7	21,9	n.r.	22,0	n.r.	21,7	n.r.	21,8	n.r.	21,7
S10	22,0	n.r.	22,1	n.r.	21,8	n.r.	22,2	n.r.	22,0
S13	21,8	n.r.	22,0	n.r.	21,9	n.r.	22,2	n.r.	22,1
	22,3		22,2		22,0		22,1		22,1
	22,5		22,1		21,9		22,0		22,1
	22,0		22,2		22,1		21,9		22,1

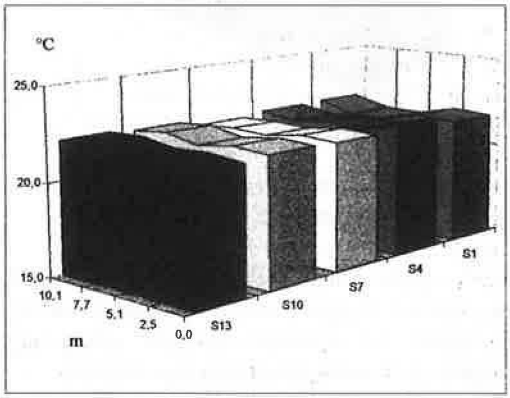

Fig. 13 - Mean temperature values (°C) - h= 1,25 m - april 96

The data, at 3 *m* from the floor, just confirm the above trend and are shown in Figs. 8 and 9. The third survey was carried out in April with external temperature of about 20 °C. Two heights, 0.15 and 1.25 *m*, were considered and less measurement points was utilised (Figs. 10, 11, 12 and 13). The overall air movement, in this case also, was from the altar towards the entrance, with a pronounced left component

As expected the velocity are lower and the temperatures higher than in the second survey This can be observed in Figs. 12 and 13 at 1.25 *m* from the floor.

A summary of walls, ceiling, floor temperatures, as obtained by infrared thermography, is given in Table 1: are reported average values of the air temperatures at 1.25 *m* from the floor and the inlet of the working fluid.

the heating plants is efficient in terms of air temperature provided.

The complete structure of the air movement within could not be detected due to the size of the height of the hall (22 m at the top of the vault). However, it is possible to infer from the data the formation of a large convective cell filling the whole ambient, characterized by horizontal current at the living quotes which should be balanced by a reversed current at the vault level.

The literature indicates that the leading parameters for natural convective circulation in enclosures is the Grashof number *Gr*. This is based on the leading temperature difference and third power of the vertical dimensions, as follows:

$$Gr = \frac{gL^3 \beta \Delta T}{\nu^2}$$

Tab. 1 - Mean temperature (°C) of the different internal structures of the Church, of internal, external air and heating fluid

	FEBRUARY	MARCH	APRIL
Nave floor	20 ÷ 21	23,5 ÷ 24	25
Altar zone floor	14 ÷14,8	16,4 + 17	18 ÷18,5
Altar corridors	20 ÷ 21	25	26
Ceiling	12,5 ÷13,5	17 ÷ 18	18,5 ÷ 19
Raised structures	15,5 ÷12,5	18,5 ÷17,5	19
Closure walls	20	23	25
Air ambient	17	20	22
External air	0 ÷ 2	16	20
Heating fluid	38	38	38

It can be note that the latter temperatures remain constant throughout the whole heating period, due an incorrect setting of the temperature controller.

The maximum difference between the ceiling and the floor was 8 °C in February. In March and April this dropped to 6 °C even if the ceiling temperature was as high as 18-19 °C.

DISCUSSION

The whole experience demonstrates that the introduction of a new radiant panel heating system originates the uncomfortable conditions within the church. These derive from the very high velocity and turbulence level at the living quotes. On the other hand

Using the temperature difference between the floor and the ceiling as ΔT and the average height of the vault as L, it is found that the Grashof number is as high as 10^{13}. Such a very high value is no only sufficient to promote and sustain a convective cell but also corresponds to high turbulence levels [1]. That it is coeherent with the experimental data. This basic model is, however, influenced by a number of secondary elements, whose relevance is impossible to predict for the time being. These are:

- the temperature of the vertical surfaces which vary during day and along the season. The lateral temperatures actually influence the direction of the circulation;

- the presence of large windows in the upper part of the enclosure which locally affects the vertical wall temperatures;
- the presence of non heated areas of the floor;
- the complex geometry of the ambient with columns and secondary chapels in the lateral naves.

It is therefore evident that the above scheme is not sufficient to explain all the characteristics of the problem. In fact the Grashof number does not change too much during the heating period, while qualitative and quantitative differences are stressed by the experimental data.

CONCLUSIONS

The results of the experimental campaign carried out in the church of S. Maria della Pietà in Bologna can be synthesized as follows:

- horizontal air currents are present at the living quotes with prevailing direction from the entrance towards the altar zone in February. The current reverses in March and April;
- velocities are particularly high in February with a maximum of 33.3 cm/s. The turbulence intensity is also very high, up to 30%, in this period. Lower velocity and turbulence levels are detected in subsequent surveys;
- pronounced velocity and temperature non-uniformities are detected in February.
- longitudinal lines with maximum temperature and minimum velocity are observed in correspondence to central columns at the end of the congregation area (in evidence in fig. 1);
- the internal surface temperatures are quite different all along the heating period with a maximum difference temperatures of 8 °C between the heated floor and the main vault.

The above effects are linked to the presence of a large convective cell filling the church enclosure. This is promoted by the temperature difference between floor and ceiling, but is definitely affected by a number of secondary elements which probably contribute qualitative and quantitative modifications to the flow structure.

The complexity of the problem imposes the necessity of the use of CFD modelling .

REFERENCES

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