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A METHOD TO COMPARE COMPUTATIONAL FLUID DYNAMICS AND MULTIZONAL DYNAMICS SIMULATIONS IN BUILDINGS PHYSICS

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ABSTRACT

This paper focuses on the development of a new evaluation method that combines data obtained by two different approaches: "multizonal dynamics" and "computational fluid dynamics (CFD)".

This research is a part of a project whose the main objective is to define guidelines for architects and buildings engineers. This guidelines aims at determining the adequate approach needed to evaluate the occupant thermal comfort and the building energy consumption for cooling and heating.

In this context, the first step of our research consisted in comparing results obtained with measurements, with a CFD approach (through FLUENT simulations) and with a multizonal approach (through TRNSYS simulations). At this aim, the study selected published reference cases in order to encounter:

- heterogeneity of physics phenomena involved in building physics: free-float, mechanical ventilation, natural ventilation, radiating walls.
- diversity of scales: a single room, partitioned building, unpartitioned building, sunny atrium.

These cases were evaluated by both types of simulations, CFD and multizonal. Comparing the results of simulations with experimental data published in these reference cases, CFD simulations appear to give really accurate results but it is not the case for all multizonal analysis. However CFD needs more runtime than multizonal approach and needs more technical knowledge to implement simulations. Indeed, multizonal approaches are often more user-friendly and intuitive for architects than CFD.

The second phase of this research consisted in bringing out the complementarities of both simulations methods. In order to achieve this goal, a method to evaluate the matching between CFD and multizonal results is suggested in this paper.

Specifically, the usual confrontation of absolute differences and relative errors was completed with a superposition of the spatial representation of temperature for a building section, resulting from each method (CFD and multizonal). The discussion argues the spatial match between FLUENT and TRNSYS results, for the total thermal zone and for the occupied zone only. Highest precision is achieved, in the occupied zone, where it has a real impact on people comfort. This combined representation of results improves the appreciation of the multizonal evaluation of the mean ambient temperature.

INTRODUCTION

Due to growing interests in environmental performance of buildings, building physics simulations are more and more used and need to be more accurate. Basically, there are two kinds of mathematical approaches: "multizonal dynamics" and "computational fluid dynamics (CFD)". Each approach leads to some advantages and disadvantages such as the accuracy of the results and the computational runtime. In this context, this research brings out the complementarities of this both approaches by defining a method to evaluate the matching between CFD and multizonal results.

METHODOLOGY

The purpose of this study is to evaluate a case study using CFD and multizonal approaches. Both approaches are confronted with measured results (flow and temperature) and their accuracy is discussed.

The comparison is based on an evaluation of absolute differences and relative errors. But a graphical representation of temperature results is also suggested. This confrontation method superposes the spatial representation of the temperature results of a building section and discusses the spatial match between CFD and multizonal results. This graphical confrontation is suggested in order to bring some nuance to the comparison of the two approaches. This method includes three steps.

The first step is the definition of an "occupied zone". The idea is that a highest precision in the results must be achieved in the zones highly occupied by the workers and which must, thus, offer thermal comfort to the occupant. Considering the European Standard EN 13779 on Ventilation and Air-Conditioning Systems [1], the occupied zone considered in the study is presented in Figure 1.

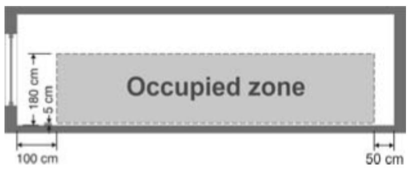

Figure 1: occupied zone considering the EN 13779 norm

The second step of the study is the representation of measured values. Considering the great accuracy of the CFD simulation and the limited number of measuring points, results obtained with the CFD approach were chosen to represent temperatures.

The third step consists in the representation of multizonal results. In order to represent the single value obtained with multizone approaches, an accurate range around this value was defined. Since the objective of this kind of simulation is to discuss thermal comfort, results must allow the identification of the comfort zone such as those described in European Standard EN 15251 [2]. The gap between different comfort zones is one degree. Thus, numerical results with an error less than 0.5° are tolerated in comparison with experimental data.

MATERIALS

Published reference cases

In order to validate the CFD approach for the evaluation of building physic phenomena and to confront the CFD to the multizone approach, we first selected published reference cases to compare simulation results with experimental results of some typical applications in building physics. Details about the selected literature have been previously published [3]. In this paper, only results obtained by Walker [4] thanks to CFD simulations and measurements on a scale model, for an unpartitioned building, with natural ventilation, are considered.

Software

Software used in this research are FLUENT for the CFD approach and TRNSYS17 for the multizonal approach. FLUENT is a widely used software for studies on fluid dynamics while TRNSYS is a well established and validated dynamic multizone software [5].

Case study: an unpartitioned building

For this study, an open-space office building was chosen because this configuration is often encountered in office buildings. Figure 2 shows the geometry of the studied scale model used for the collection of experimental data [4]. A conversion was used to obtain the value at real scale. Table 1 describes the main hypothesis done to run models.

Hypothesis	Walker	Trnsys	Fluent
Boundary temperature [°C]	13	13	13
Air supply temperature [°C]	13	13	13
Internal gain by zone [W]	500	500	500
U wall [W/m²K]	0.39	0.39	Adiabatic
South fenestration by zone [m²]	0.0336	0.0336	0.0336
North fenestration by zone [m²]	0.04788	0.04788	0.04788
Inlet speed [m³/s]	0.1	0.1	0.1
subdivision	-	5 zones	1 244 722 cells

Figure 2 and Table 1: scale model geometry and main hypothesis

The referenced study presented hypotheses used to realize measurements in a scale model and CFD evaluation. Hypothesis for the new CFD model to reproduce Walker's results were available. But, some supplementary assumptions are needed to achieve the multizonal model:

- the simulation time step is 0.1h. The results are examined after a 200 hours long preprocessing period to avoid any impact of chosen initial conditions,

- airflows are evaluated thanks to the Trnflow add-on to TRNSYS. Where air supply is modeled as a fan, openings between thermal zone and exhaust openings are modeled as "large openings" with a constant discharge coefficient of 0.6,

- no solar radiations is considered in the model and external temperature is constant.

RESULTS

Conventional comparison – Flow

In Figure 3 presenting results obtained for multizonal and CFD approaches, we observe that TRNSYS results are consistent with FLUENT for the inlet flow but are not consistent for the outlet flow. Indeed, absolute flow differences are 6 in the south zones and vary between 209 and 220 in the north zones.

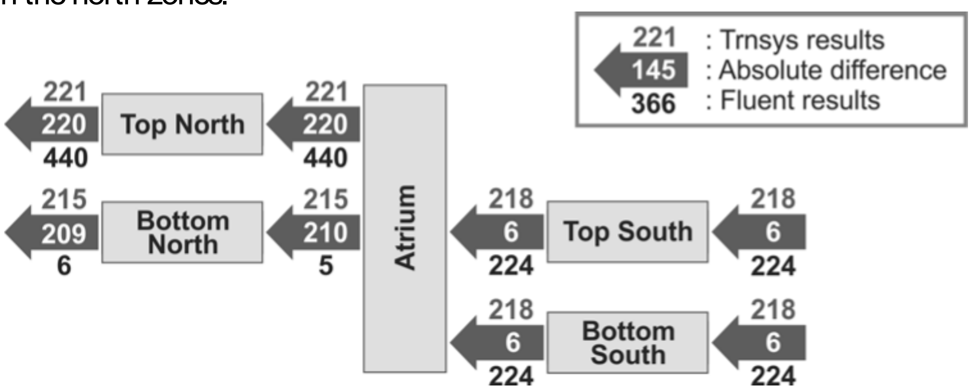

Figure 3: Net flows obtained with CFD and multizonal approaches and the absolute differences between these results

TRNSYS results spread equally the flow between the bottom and top North zone. On the other hand, FLUENT results show a different pattern. Indeed, the net flow mainly goes in the top North zone and almost zero in the bottom North zone.

For the inlet flow, the little difference is due to the density chosen for the incoming air 1.204 kg/m³ for TRNSYS and 1.225 kg/m³ for FLUENT. For the outlet flow, the difference is due to the simulation of the atrium as a unique thermal zone. This neglects the impact of thermal stratification and of the conservation of motion. Indeed, a thermal stratification occurs in such an atrium and the impact of this stratification on the flow direction explains CFD results

Conventional comparison – Temperatures

Figure 4 shows temperatures obtained experimentally by Walker [4], using CFD and multizonal simulations. The atrium temperature was not measured by Walker, however we computed it.

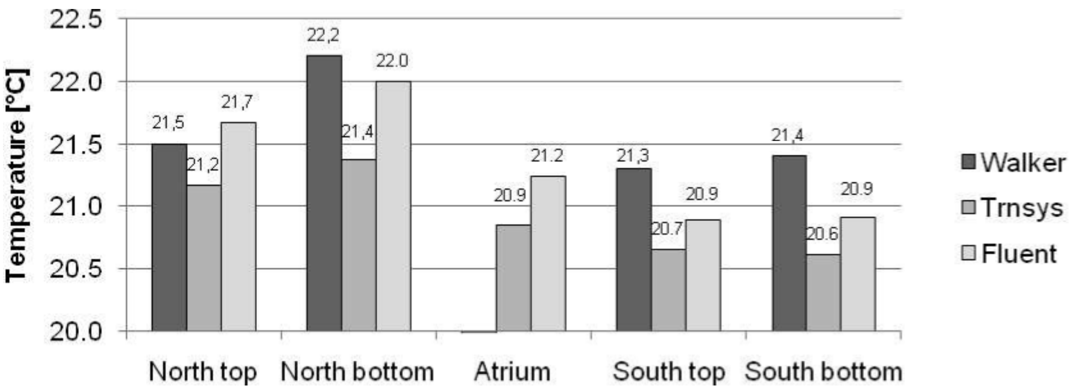

Figure 4: temperatures obtained experimentally by Walker, numerically by CFD and by multizonal.

We observed that temperatures obtained with FLUENT are, for each zone, superior to temperatures obtained with TRNSYS. Moreover, measurements done by Walker are generally superior to results obtained by simulations.

Table 2 presents absolute and relative differences between measurements done by Walker and numerical results (multizonal approach with TRNSYS and CFD approach with FLUENT).

	Absolute difference Walker-TRNSYS	Absolute difference Walker-FLUENT	Relative difference Walker-TRNSYS	Relative difference Walker-FLUENT
Top North	0.33	0.17	2 %	1 %
Bottom North	0.83	0.2	4 %	1 %
Atrium	-	-	-	-
Top South	0.65	0.41	3 %	2 %
Bottom South	0.79	0.49	4 %	2 %

Table 2: absolute and relative differences

Absolute differences between TRNSYS results and measurements vary between 0.33 and 0.83°C. The precision objective: 0.5°C, as explained in the methodology, is not achieved. Absolute values from FLUENTresults vary from 0.17 to 0.49°C. In this case the precision objective is achieved. The relative errors vary from 2% to 4% for Walker- TRNSYS comparison and from 1% to 2% for the Walker-FLUENT comparison.

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Graphical confrontation method - Temperature

As explained in the methodology we consider that the acceptable range of accuracy is given by the numerical results +/- 0.5°C. By this way, ranges in the five simulated zones are defined as follow:

Top North :	[20.7°C ; 21.7°C]	Top South:	[20.2°C ; 21.2°C]
Bottom North :	[20.9°C ; 21.9°C]	Bottom South :	[20.1°C ; 21.1°C]
Atrium :	[20.4°C ; 21.4°C]		

Figure 5 illustrates, for each zone:

- the temperature distribution in the central plane of the building obtained with CFD;
- the matching of multizonal results (range of temperature defined above) for each occupied zone (shaded area),
- the matching of multizonal results for each zone (white line).
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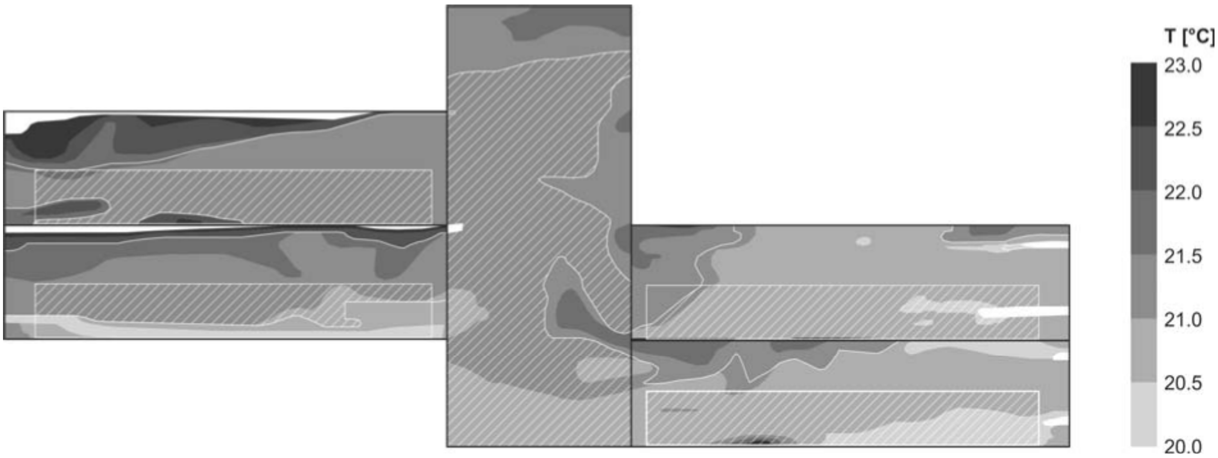

Figure 5: The temperature distribution in the central plane of the building section obtained with CFD and the matching of the multizonal results for each zone (white line) and for each occupied zone (shaded area).

Table 3 provides the percentage of space where the multizonal approach is correct for each zone and each occupied zone.

x %	Total zone	Occupied zone	x %	Total zone	Occupied zone
Top North	66	90	Top South	81	92
Bottom North	68	63	Bottom South	85	100
Atrium	74	-			

Table 3: percentage of matching between the multizonal and CFD results

DISCUSSION

When analyzing absolute differences and relative errors, CFD leads to more accurate results. However by the graphical superposition of CFD and multizonal approaches, the method indicates that the multizonal approach gives matching between CFD and multizonal results for more than 66% for each zone. Furthermore, for the occupied zone, better matching is obtained.

Indeed, for the bottom South zone, multizonal results correspond to 100 % of CFD results in the occupied zone. For the South and North top zones 92 % and 90 %, respectively, of multizone results match with CFD results for occupied zones. However, the bottom North zone presents a different pattern: indeed, only 63% of the multizone results match with the CFD results. The bottom part of the occupied zone is over estimated by multizonal approach. In the case of an office building, this may lead to a thermal discomfort.

In general, better temperature matching is obtained in the South zones where flows were better estimated by multizonal approach.

Despite that, absolute differences between measurements and multizonal approach results are 0.79 for the bottom South zone and 0.83 for the bottom North zone, while the matching in the occupied zone is 100% in the bottom South zone and only 63% in the bottom North zone.

CONCLUSION

Absolute differences and relative errors are efficient tools to discuss mathematical quality of approaches, but do not exactly reflect the pertinence of these approaches. The pertinence that we defined as the ability to give a useful indication for the designer is more efficiently evaluated if approaches are compared for relevant values. Relevant values, when speaking of thermal comfort, are those related to occupied zones and allowing the identification of normatively defined comfort zones.

The graphical superposition of CFD and multizonal approaches allows bringing out some nuances to the comparison of these approaches and improves the appreciation of the multizonal evaluation of the mean ambient temperature.

In fact, for the example presented in this paper, multizonal errors are smaller if compared to measurements in the occupied zone only. Moreover, multizonal approach results are representative of a significant part of that occupied zone. This argues for the pertinence of this approach despite the disappointing values indicated by traditional "error based" comparison.

ACKNOWLEDGEMENT

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http://www.project-simba.eu

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