INDUSTRIAL APPROACH FOR CFD MODELLING APPLICATIONS FOR AIR-CONDITIONING AND HEAT EXCHANGER SYSTEMS

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1. INTRODUCTION

In the field of air conditioning, industrial manufacturers are subject to close competition due to market globalisation. Nowadays, to be able to sell a product, it must not only fulfil its technical purpose, but it must also stand out from competitive products through its secondary qualities. In this way, manufacturers' slogans no longer refer to their products' technical performances, but also to their compact size and the comfort (acoustic, thermal) that they offer to their users.

In parallel, national and international regulations are becoming increasingly strict. They apply equally well to the energy efficiency of units and their impact on the environment (limitation of greenhouse effect fluids) and on users' health (indoor thermal and acoustic quality).

Thus, the increases in the demand for comfort and regulations have compelled manufacturers to optimise their products, which requires increasingly extensive knowledge of the physical phenomena involved.

The aim of a manufacturer such as CIAT is to develop products that meet market demands. This aim led at first to the use of experimental methods. This pragmatic approach proved to be effective for some years. It was soon followed by the development of analytical tools enabling the optimal use and extrapolation of experimental results.

Numerical applications emerged on the market some twenty years ago. Initially reserved for academic research and technical centres, they have made their way into the industrial sector, particularly due to the work devoted to improving the ergonomics of numerical products and considerable progress in the IT sector. Finally, manufacturers quickly understood that using these methods could induce a significant reduction in development costs and times.

2. HOW TO USE NUMERICAL APPLICATIONS?

At the present time, there are various methods used to model a continuous physical problem in discrete mode. In this way, the DNS (Direct Numerical Simulation) method, despite its great precision, is still used only by university laboratories due to its cost. The LES (Large

Eddy Simulation) method [1] is under development and finalisation; it is still confidential and remains reserved for academics.
In reality, given the cost constraints, the most widely used CFD applications are based on statistical modelling of the physical problem to be processed. This approach is based on simplifying hypotheses. In this way, turbulence can be processed with different models: k-ε, k-ε RNG (Renormalization Group Methods) [2] and k-ε Bas-Reynolds.

Therefore, before it is possible to use numerical applications in a reliable and productive manner, it is necessary to validate the calculation hypotheses. This is one of the objectives of the conventional experimental approach. While, in the long term, numerical calculation enables reduction of test campaigns required to optimise products, it initially requires sufficiently accurate measurements to be able to validate the hypotheses and results of the numerical calculation.

In addition to CFD applications, it is also possible to mention nodal models and the zonal model approach. The former are essentially used for thermal codes in the construction sector, and include COMIS (Feustel, 1990), AIRNET (Walton, 1989) and HVACSIM (Park, 1985) and TRNSYS (TRNSYS, 1979). For zonal models, the conservation equations are integrated in a coarse mesh. These applications, which emerged in the 1970s with the work of Lebrun [3], were developed by Inard [4], [5] and Rutman [6], particularly to process the modelling of heated and air-conditioned rooms.

3. EXAMPLES OF USE OF NUMERICAL MODELLING TOOLS

CIAT approaches the optimisation of its products on 3 levels:

1. Component optimisation

The performances of an air conditioning unit are closely dependent on the performances of its constituent devices: heat exchangers, compressors and fans. As a result, in order to optimise the final product, it is necessary to optimise the selected components in a suitable and rigorous manner.

2. Complete unit optimisation

Once the components have been selected, the manufacturer can assemble them. One of the major problems that can encounter is the optimisation of the assembly. In some cases the complete unit may offer disappointing performances compared to those theoretically obtained by combining the various components. Conventionally, this degradation in performance is referred to as the *"system effect"*. These system effects may be of any kind (ventilation, thermal, etc.). To control them represents a significant part of the work devoted by CIAT to optimising its products.

3. Prediction of indoor environment quality

Finally, CIAT is working increasingly with a view on advising the customer about the most suitable product to use, not only in terms of technical performances but also in terms of user requirements with respect to indoor environment quality.

In this article, we will present three industrial numerical application approaches.
Plate exchanger optimisation

In a recent technical publication, we demonstrated the benefits of numerical modelling, which has become a powerful tool to design, optimise and even view the operation of various heat exchangers [8].

The present publication essentially covers plate exchangers, for which the market is of growing interest in terms of performances, compared to tubular exchangers. However, their potential application in cooling units and heat pumps is limited by some phenomena, which have not been sufficiently controlled to date, such as two-phase distribution. As represented in Figure 1, this phenomenon is result of presence of two contradictory phenomena, i.e.:

- reduction of the inlet flow rate to improve the flow rate distribution
- increase of the homogeneous flow rate to avoid phase separation, which need to be controlled simultaneously.

In order to solve this problem, we opted, among other things, for the application of the CFD technique, used to understand experimental results and resolve flow phenomena inside plate exchanger manifolds using the non-destructive approach. For this, the Heat Transfer Laboratory of CIAT R&D Centre has been working for many years on simulating the two-phase flow of the refrigerant inside tubes and plates operating in evaporation and condensation mode.

This research was carried out with the specific CFD code, which enables a unique approach, accounting for the physical phenomena encountered in two-phase heat transfer. In effect, in the case of variations of flow type, where a non-compressible flow may coexist with a highly compressible diphase flow, modelling is not simple. It becomes more complex with heat conduction through a structure, with 1D or 2D behaviour, which is frequently encountered in thin plate exchangers.

In this way, figure 2 shows a two-phase flow in an inlet tube. Unlike most of the codes available on the market, which only offer one CFD solver type for all flow types, this one offers up to eight simultaneous numerical models [9], [10].
In the case of heat exchangers, the correct methodology consists of coupling flow resolutions using a finite element solver for the transient structural or modal analysis in conjunction with an implicit CFD solver for rapid flows and an ALE (Arbitrary Lagrange Euler) formulation to process free surfaces.

This approach enables adequate processing of each phenomenon and, accordingly, offers more reliability in the results of optimisation of future generation exchangers. In Figure 3, we have represented an example of two-phase modelling inside a feed pipe. Phase separation can be observed in the lower part of the manifold, initially detected by differences in flow rate. Therefore, using the CFD approach, we were able to optimise the geometric configuration of the manifold to obtain a practically homogeneous flow.

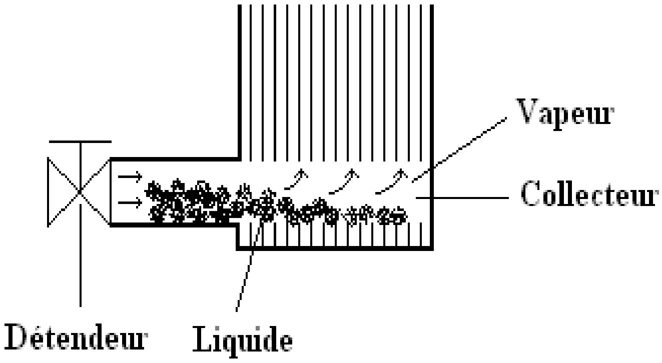


Figure 1. Simplified diagram of a distribution phenomenon

Figure 2. View of two-phase flow inside a tube

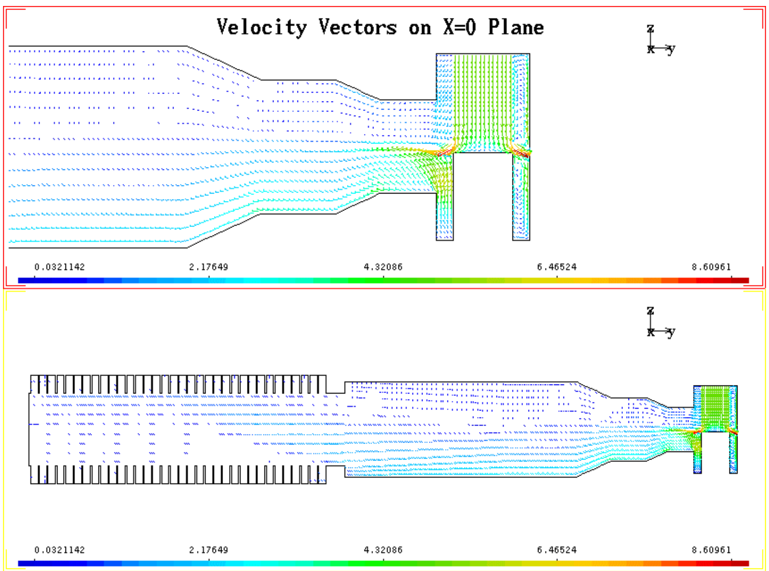


Figure 3. Two-phase flow modelling in the inlet manifold of a plate exchanger

System effect analysis

Given the wide diversity of air conditioning systems, there are many problems that the numerical approach may help solve. We shall take the problem of the mixing box as an example. As a general rule, an air handling unit used for building ventilation and air conditioning is composed of various boxes which have one or more functions: circulation, filtration, heating, cooling, heat recovery, humidification, dehumidification and air mixing. The mixing box is used to mix outside air and recycled air. In general, it is composed of two flap dampers, one per air flow and one mixing chamber.

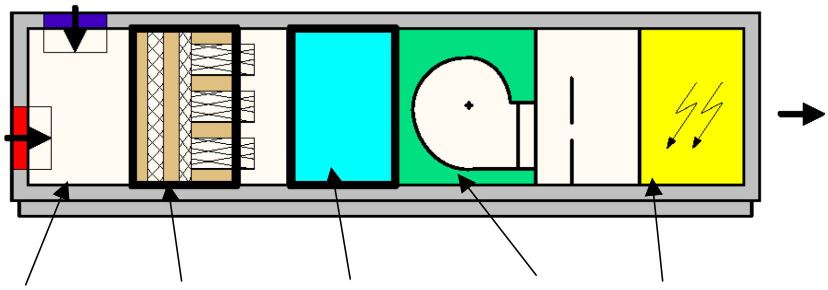


Figure 4: Example of air handling unit configuration

This box must be optimised to obtain a homogeneous temperature and air velocity distribution at the exchanger inlet. This is one of the parameters that govern the level of performance of heat exchange. In addition, the presence of non-irrigated zones on the exchange surface may in some cases induce the deterioration of the equipment (e.g. freezing of exchange batteries). Moreover, European certification of this equipment is becoming a major sales argument. In this way, the standard NF EN 13053 [14] defines criteria used to check mixing quality and classifies equipment according to these criteria. For this type of problem, the systematic experimental approach cannot be envisaged since the number of parameters to be optimised is too high. For the damper itself, it is also necessary to take the flaps, along with their layout and orientation into consideration. For the mixing chamber it is necessary to envisage the relative position of the dampers. For this reason, CIAT offers several configurations.

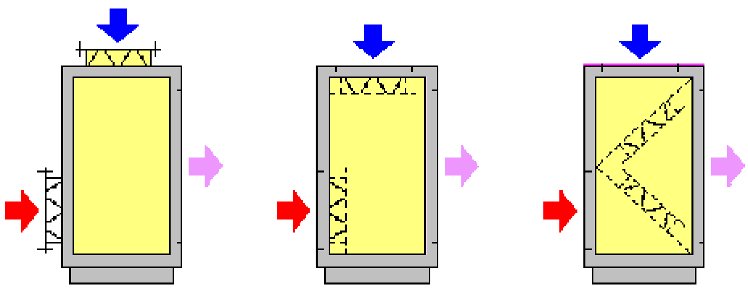


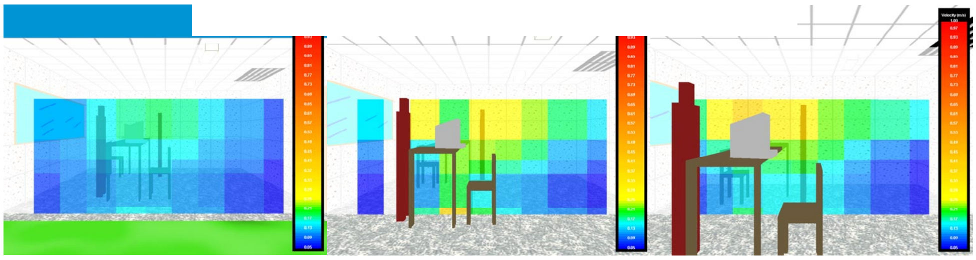
Figure 5. Some mixing box configurations

Finally, this optimisation must also take into consideration the different air modes defined by the combined flow rate and temperature for each of the air inlets. Therefore, to deal with this problem, CIAT envisages a numerical approach and a parallel experimental approach for some of the most representative cases. The results obtained are compared to select the most realistic calculation hypotheses. The optimisation work is then carried out using numerical methods.

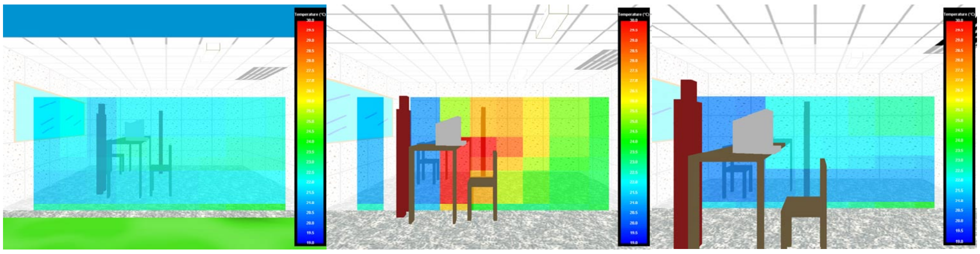
Prediction of indoor environment quality

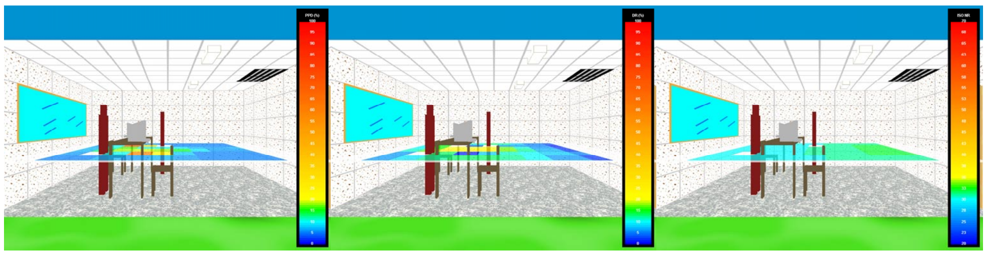
Following 1973 and the oil crisis, the French government decided to reduce building energy consumption. We moved from an insulation level requirement to an energy consumption requirement. This concern was not only found in France, but also in Europe and throughout the world. Thus, many countries have set up research programmes, including the work by NIST and Yale University with the development of multi-zone modelling applications with the CONTAM programme and use of 3D LES with the EXACT programme [11], [12], [13]. In parallel, Europe worked on the development of various standards. In this way, over the last ten years, in line with European and international concerns, the CIAT laboratory has been working on indoor environment quality. Several authors such as Fanger (Fanger-1970) have demonstrated that office users are subject to various types of local discomfort caused by temperature, draughts and noise. Therefore, to improve comfort, we can use different air conditioning systems. For example, in the summer, a cold air stream sent into a room generates thermo-anemometric fields and an acoustic pressure field. To minimise various risks of local discomfort, these different indices must be as homogeneous as possible. Rutman [6] conducted experimental studies to be able to associate air flow characteristics with a global approach to comfort including thermal and acoustic comfort. This resulted in us developing a zonal model to be able to predict the global approach to comfort. A comparative study [7] of six experimental and numerical cases demonstrated that this model is a satisfactory way to predict thermal and acoustic comfort. We simulated the operation of a non-standalone ceiling-mounted air conditioning terminal unit equipped with a built-in adjustable multi-nozzle grille. The air-conditioned office is a 3-grid type, with a 1.35 m grid, a floor area of 20 m^2 and a ceiling height of 2.50 m. This office is equipped with a table, two chairs, two computers and two lights with a total load of 1850 W. Moreover, two users occupy the office. The figure below contains the air velocity and air temperature field distribution. In addition, in accordance with the standard ISO 7730 [15], we have presented the progression of the Predicted Percentage of Dissatisfied (PPD), which is used to define the number of subjects dissatisfied with the thermal sensation in a room. We have also presented the repartition of the Draught Rating (DR), which, in accordance with the same standard, is used to quantify the number of subjects dissatisfied with the draught sensation. Finally, we can observe the progression of the Noise Rating (NR) obtained on the basis of data from the International Standardisation Organisation with the recommendation ISO R 1996 [16].

Evolution of air velocity inside room (m/s)



Evolution of air temperature inside room (°C)





LE PPD **LE DR** **LE NR**

Figure 6. Progression of basic values and Comfort indices

4. CONCLUSIONS

Manufacturers aim to develop products that meet users' expectations. Like all the other departments in a company, the Research and Development department must optimise its technical-economic ratio. For this reason, CIAT uses numerical modelling applications as a complement to the conventional experimental approach. Through the three examples presented in this article, we can see that these applications are used to improve the understanding of physical phenomena, optimise product development time and also to fulfil our obligation on an advisory level. In this way, if these high-performance calculation methods are used as part of a rigorous validation process adapted to each type of application, they can render a significant service to industry.

REFERENCES

[1] Friedrich, R.: *DNS and LES of incompressible turbulent flows*, 4[ième] Ecole de Printemps de Mécanique des Fluides Numériques, Carcancs-Maubuisson, 1995, pp 67

[2] Yakhot, V., Orszag, S.A.: *Renormalisation group analysis of turbulence*, I. Basic Theory, Journal of science computing, 1, 1986, pp 3-51

[3] Lebrun, J. *Exigences physiologiques et modalités physiques de la climatisation par source statique concentrée*, Thèse de Doctorat, Université de Liège, 1970, 113 p.

[4] Inard, C., Molle, N., Allard, F.: *Etude du couplage thermique entre des corps de chauffe et un local*, Revue Générale de thermique, mars 1991

[5] Inard, C., Meslem, A., Depecker, P. *Energy consumption and thermal comfort in dwelling-cells: a zonal model approach*, Building and Environment, V. 33, n°5, 1998, p.279-291.

[6] Rutman, E.: *Contribution à l'évaluation de la qualité des ambiances intérieures climatisées*, Thèse de Doctorat, Université de la Rochelle, 1992

[7] Rutman, E., Inard, C., Bailly, A., Allard, F.: *Prediction of global comfort in air conditioned building with a zonal model*, Indoor Air 2002, Monterey (USA), p. 724-729, june 2002

[8] Bailly, A., Fournier, F., Jurkowski, R.: *Quelques études de cas d'applications industrielles de la mécanique des fluides numérique en transfert thermique*, European Community on Computational Methods in Applied Sciences, Energy Efficiency in Process Technology, ECOMASS 1996, Paris

[9] Patil, S., Murthy, A., Dagba, Y., Tripathi, A.: *Coupled structure (FE) and fluid flow (FV) analysis for vortex-induced vibrations*, 16th International Conference on Structural Mechanics in Reactor Technology (SMiRT), Washington DC, USA, Agust 2001

[10] Suresh, K., Dagba Y., Tripathi A.: *Tubular structure deformation under the thermal loads of two fluids*, 4th International ASME/JSME/KSME Symposium on Computational Technology (CFD) for Fluid/Thermal/Chemical/Stress Systems and Industrial Applications, Vancouver, CANADA, August 2002

[11] Axley, J.W.: *New mass transport elements and components for NIST Indoor Air Quality Model*, Yale University, 1995

[12] Emmerich, S.J.: *Application of a LES Model to study Room Airflow*, ASHRAE Transactions, 9pages, 1998

[13] Persily, A.K.: *Input data for multizone airflow and Indoor Air Quality Analysys*, raport NIST 6585, 33pages, 2001

[14] *Norme NF EN 13053: Ventilation des bâtiments - Caisson de traitement d'air: classification et performances des caissons, composants et section,* Association française de Normalisation, Paris, Janvier 2002

[15] *Norme NF EN ISO 7730: Ambiances thermiques modérées: détermination des indices PMV et PPD et spécifications des conditions de confort thermique*, Association française de Normalisation, Paris, décembre 1995

[16] *Assessments of noise with respect to community respons*. Technical comitee ISO/TN43 Geneva Switzerland, 1971