From Technical Appraisal of Demand-Controlled Ventilation Systems to Indoor Air Quality Assessment Using the Thermo-Hygro-Aeraulic code MATHIS

François Demouge[1], Julien Piriou[1]

1: CSTB
11 rue Henri Picherit – BP 82341
44323, Nantes cedex 3

SUMMARY

The communication presents the Technical Appraisal Procedure followed in France for Demand-Controlled ventilation systems through the illustration of the use of a thermo-hygro-aeraulic nodal model called MATHIS developed by CSTB. The calculations methodology is described. Its application is illustrated for different family of ventilation systems currently under the scope of the procedure. The needs and the current developments for a better modelling of Indoor Air quality are lastly exposed.

KEYWORDS

Ventilation system, indoor air quality, nodal modelling tool

1 INTRODUCTION

In France, the ventilation of dwellings is mainly defined by prescriptive rules (Ministère Urbanisme et logement, Energie, Santé, 1983). Those rules describe the architecture of an overall and permanent ventilation system by means of air inlets placed in principal rooms (namely living and bedrooms) and air outlets set up in technical rooms (kitchen, bathroom and toilets). The volume flow rates at outlets are defined as function of the number of principal rooms inside a given dwelling. The rules quantitively set the minimal flow rates for the kitchen and the whole dwelling as well as higher flow rates that the system must be able to independently reach in every technical room. In case of an automatically controlled ventilation system, the minimal flow rates can be lowered under the authorization of the national regulation body. In support of these prescriptive rules, a set of standards guarantee the correct operation of the systems by providing rules for the system design, see for example (AFNOR, 2013) (AFNOR, 2010), and the components qualification tests, see for example (AFNOR, 2005).
In this regulatory and normative background, the Technical Appraisal procedure offers to the market a means to warranty the performance of the Demand-controlled ventilation systems and to valorise them in terms of energy savings within the framework of the French Thermal Regulation. The expert commission responsible for the evaluation procedure (commission GS14.5) defines the set of requirements that a given system must meet and the calculation procedure to be followed to justify this respect for each family of systems, see for example (Groupe Spécialisé n°14.5, 2016).
In recent years, an effort has been made by CSTB in partnership with French manufacturers to develop the MATHIS software: a first objective was to use the same tool for all families of ventilation systems involved in the Technical Appraisal procedure. A second objective was to

be able to improve the tool as innovation occurs, whether in terms of products or evaluation rules.
In the next sections, we briefly describe the calculation method and the specificity of the use of MATHIS for each family of ventilation systems.

2 CALCULATIONS MADE UNDER THE TECHNICAL APPRAISAL PROCEDURE

2.1 The software MATHIS

The airflow model of MATHIS is a nodal model based on a simplified representation of the thermo-aeraulic phenomena inside a building (Demouge, MATHIS - Technical Guide, 2017). The modelling principles are the same as other tools such as SIREN (Akoua, 2009), CONTAM (Walton & Dols, 2005) or COMIS (Feustel, 1992)
Nodes represent the gas volumes of a building's rooms and portions of ventilation network. Solving conservation of mass and internal energy in the nodes allows to reach the pressure, the temperature and the mass fractions of the chemical species in the corresponding volumes. The density is deduced from the state equation of perfect gases. A humidity model, considering saturation vapor pressure and condensation / release of water vapor from the liquid phase, allows to deduce the relative humidity.
Branches represent the aeraulic connections between these volumes. Several branch models are implemented. Most branches are simply defined by a flowrate as function of pressure, such as the orifice equation or by a fixed flowrate independent from pressure. However, ducts and fans found in ventilation networks are described by their pressure loss or gain as function of flowrate. For these, the writing of the conservation of the mechanical energy (Bernoulli equation) allows to access to their flowrate.
This airflow model has been validated against wind tunnel tests (Demouge, Le Roux, & Faure, Numerical Validation for Wind Driven Ventilation Design, 2011) (Demouge & Faure, Natural Ventilation Design for Low-Rise Building: Comparison between a Nodal Model and Wind Tunnel Tests, 2013). The model also has been validated against the software SIREN (Demouge, Faure, & Piriou, Confrontation des logiciels MATHIS et SIREN, 2013), which was the CSTB's tool previously used for the Technical Appraisal procedure, and the CFD software FDS from NIST (Lafféter, 2015).
A thermal model is coupled to the aeraulic model to represent the heat exchanges between the gas volumes and the solid walls. It allows to consider the convective exchanges between surfaces of the walls and gaseous volumes, the radiative exchanges between the external walls and the near environment, the celestial vault and the sun, the radiative exchanges between the walls of a same room as well as the diffusion of heat in the thickness of the walls. This thermal model has been validated by the comparative method BESTest defined by IEA (Clerc & Demouge, 2016).

2.2 Calculation principles

The main objectives of the calculations are:

- Check the efficiency of the system in the management of an acceptable Indoor Air Quality (IAQ);
- Quantify the performance of the system with regards to energy savings.

The calculations are made during the heating season, from October 1st to May 20th.
The system's efficiency on IAQ is based on two criteria. The first one is based on the temporal evolution of the volume fraction of CO_2 and give information on the level of air renewal during occupancy. The defined criterium considers both the duration and the level of exposure to CO_2 and must remain below 400.10^3 ppm.h "cumulated in base 2000", see Figure 1 for explanation.
The second one considers the evolution of relative humidity in technical rooms. It allows to

check the ability of the system to quickly evacuate high sources of water vapor generated by occupants' activities (cooking, showers, washing and drying clothes, ...). The criterium states that the number of hour with a humidity higher than 75% must remain below 600 in the kitchen and 1000 in the bathroom for the whole heating season.

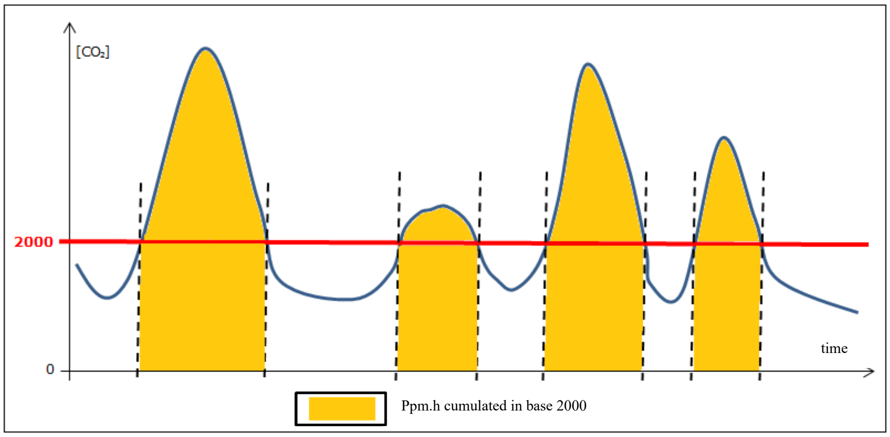

Figure 1: calculation of the CO2 criterium

Those criteria are calculated based on deterministic scenarios. Various sizes of dwellings are considered, from 1 principal room up to 7, with various number of technical rooms and different indoor architecture configurations (1 or 2 levels). Façade leakages are defined as well as occupancy (number of occupants, H_2O production associated to housing activities, hygroscopy of furniture, …). Outdoor conditions such as wind speed and direction, temperature and humidity, solar radiation, etc, are defined regarding the reference city used in the procedure.
In addition, the energy saving performance of the ventilation system is quantified for each type of dwelling studied by the mean flowrate obtained at outlets and inlets. These flowrates are used later as input data in the Building Energy Simulations made in the framework of French Thermal Regulation (CSTB, 2010).

3 STUDIED VENTILATION SYSTEMS

Currently, the Technical Appraisal procedure has been applied for Demand-Controlled Ventilation Systems solely based on humidity-controlled flowrates. Those system are indeed widely used in France.

3.1 Humidity-Controlled Fan Assisted Ventilation Systems

For Fan Assisted Ventilation systems (exhaust or balanced), the calculations are made at the scale of one dwelling. The behavior of the ventilation network is indeed expected to be weakly impacted by outdoor conditions. Therefore, in the calculations, air terminal devices are supposed to operate at their rated pressure (around 80 Pa). Corrections are applied on the mean flowrate used for energy saving calculations with regards to fan control method and type of dwelling (individual or collective housing)

3.2 Humidity-Controlled Hybrid Ventilation Systems

Hybrid ventilation systems (systems where natural ventilation may be at least in a certain period supported or replaced by mechanical ventilation) are mainly used in reconditioning operations of collective dwellings but can also be used in the construction of new housing. The rated pressure of terminal devices of those systems is quite low, between 7 to 30 Pa. This leads to a higher versatility of the ventilation network behaviour with regards to outside conditions. Therefore, the choice has been made for the calculations to consider the system at the scale of a whole building (up to 10 levels of one dwellings each). The whole ventilation network is modelled, which allows to consider stack effect and linear and singular pressure losses. Both natural and mechanical operating modes of the exhaust fans are modelled. The results allow to check the IAQ criteria as well as the mean exhaust flowrate per dwelling.

3.3 Compatibility between Air Conditioning System and Humidity-Controlled Ventilation System

An Air conditioning (AC) system (used for heating and/or cooling) might disturb the operation of the ventilation system and is by default proscribed in dwellings fitted with a Humidity-Controlled Ventilation system.

The GS14.5 has defined a specific procedure to assess the compatibility of an AC system with a Humidity-controlled ventilation system. Full thermo-hygro-aeraulic calculations are then made to represent the detailed operation of the AC system and its interaction with ventilation. Calculations stand for the whole year with a time step of one minute. A comparative study is made to check the evolution of IAQ criteria as well as energy savings performance of the ventilation system between a house without AC system and the same house fitted with the AC system.

3.4 Needs for a better assessment of IAQ

Up to now, the IAQ criteria used in this Technical Appraisal procedure have proven to be sufficient. However, in the context of an increasing innovation from manufacturers and a growing health protection demand from end users, the need for a finer and better modelling of IAQ is rising.

A first point comes from innovation: the electronics components are cheaper, the probes for any gas are available, high progress have been made in multi-control algorithmic. This allows manufacturers to propose to the market some smart products which bring new needs in terms of evaluation. For instance, the CO_2 criterium has been defined on the knowledge and feedback from the use of one given technology of Humidity-Controlled systems. Tomorrow, the same criterium might be completely meaningless in the case of a CO_2-Controlled ventilation system set to maintain a constant CO_2 volume fraction equal to 1999 ppmv.

A second point lays on the need to offer to the manufacturers a wider range of opportunities to design higher added value products. Today in France, the sole energy savings performance is considered when choosing a ventilation system: the lower the flowrate, the higher the benefits… it sounds strange for systems whose main function is to insure sufficient air renewal.

4 CONCLUSION

This communication allowed us to illustrate the procedure used in France for the Technical Appraisal of Demand-Controlled systems which partly relies on nodal modelling of the physical phenomena involved. The limitations of the current procedure show the need for better modelling of IAQ.

In the past years, a research effort has been made by the Health & Comfort Department of CSTB in Grenoble to assess the possibility of modelling IAQ more accurately. Pollutant emission databases of building materials and furniture are available and already allow an acceptable modelling of the indoor transfer of species such as formaldehyde and total volatile organic compounds (TVOCs). Efforts are made to consider fine particles, which have complex phenomena of deposition/resuspension within the aeraulic network (ducts, air inlets, façade leakage, filters, etc.) that must be well represented. Soil pollutants such as radon are also considered by this research.

The integration of these pollutants is currently underway at CSTB Grenoble as a project called MATHIS-QAI, which also includes the definition of relevant IAQ criteria. These different developments are a step towards an IAQ-oriented ventilation engineering using suitable modelling tools.

5 REFERENCES

AFNOR. (2005). *NF EN13141 - Essais des performances des composants/produits pour la ventilation des logements.*

AFNOR. (2010). *NF E51-766 - Ventilation des bâtiments - Elements de calcul complémentaires des débits des conduits collectifs shunt en ventilation naturelle.*

AFNOR. (2013). *NF DTU 68.3 - Travaux de bâtiment - Installations de ventilation mécanique .*

Akoua, J.-J. (2009). *Utilisation du logiciel SIREN2000 version 9.0 (version CAPE).* rapport CSTB ESE/DE/PEB-09-037R.

Clerc, T., & Demouge, F. (2016). *Evaluation of the Performance of the Thermal and Aeraulic Building Simulation Software MATHIS with the BESTest Method.* CSTB, EN-CAPE 16.148 R-V0.

CSTB. (2010). *Méthode de calcul Th-BCE 2012.* annexe à l'arrêté portant approbation de la méthode de calcul Th-BCE 2012.

Demouge, F. (2017). *MATHIS - Technical Guide.* CSTB, rapport n° EN-CAPE 17.053 L - V0/EN.

Demouge, F., & Faure, X. (2013). Natural Ventilation Design for Low-Rise Building: Comparison between a Nodal Model and Wind Tunnel Tests. *Building Simulation.* Chambery, France: IBPSA.

Demouge, F., Faure, X., & Piriou, J. (2013). *Confrontation des logiciels MATHIS et SIREN.* CSTB, rapport n° EN-CAPE-189-L-V0.

Demouge, F., Le Roux, N., & Faure, X. (2011). Numerical Validation for Wind Driven Ventilation Design.

Feustel, H. E. (1992). The COMIS model. (H. Feustel, Ed.) *Energy and Buildings, 18*(2).

Groupe Spécialisé n°14.5. (2016). *VMC Simple Flux Hygroréglable - Régles de calculs pour l'instruction d'une demande d'Avis Technique.* CCFAT.

Lafféter, C. (2015). *Modélisation de l'impact de l'architecture intérieure sur la diffusion des polluants au sein d'un bâtiment.* CSTB, EN-CAPE 15.048 R - V0.

Ministère Urbanisme et logement, Energie, Santé. (1983). *Arrêté du 24 mars 1982 modifié par arrêté du 28 octobre 1983 - Dispositions relatives à l'aération des logements.* Journal Officiel du 27/03/1982 et du 15/11/1983.

Walton, G. N., & Dols, W. S. (2005). *CONTAM - User guide and Program Documentation.* NISTIR 7251, NIST.