RESHYVENT

Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables

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TABLE OF CONTENTS

1 INTRODUCTION

The activities reported in this publication find their origin in the convergence of two facts, both related to energy savings in buildings.

Firstly, hybrid ventilation has been considered as a possible solution to save energy in buildings, while increasing the indoor comfort. Between 1998 and 2002, a research project was carried out in the framework of the International Energy Agency (IEA) to develop and promote hybrid ventilation in offices and schools: HYBVENT (reference [1]). The RESHYVENT project addresses the same questions more specifically in the residential context.

Secondly, the European Commission and the European Parliament voted the Energy Performance of Building Directive (EPBD[1]) (reference [2]). Among others, this directive requires the 25 Member States of the European Union to adopt a **methodology of calculation of the energy performance of buildings** and to impose **minimum energy performance requirements for all new buildings** and **for major renovations** of larger buildings.

In the framework of the IEA HYBVENT project, a Dutch school was equipped with a hybrid ventilation system (see §3.4 page 3). At that time (1998-2002), the EPBD was not yet published, but an EPB regulation existed already in The Netherlands; it was therefore necessary to evaluate the performances of this innovative system. As it was not possible to assess the performances of the system according to the standard calculation procedure, it was necessary to use the "escape route" foreseen by the Dutch regulation, the so-called *"Principle of Equivalence"*.

For each input data, the design team collected the range of values that were scientifically justifiable (e.g. internal gains varies from 36 to 51 W/m²) and created three sets of assumptions: the first set included a value in the middle of the range of each input data (e.g. internal gains = 41 W/m²), the second set included the extreme value of the range that was known to favourable to show energy savings (36 W/m²), and the third set included the other extreme value of the range (51 W/m²). The calculated energy savings (compared to a mechanical ventilation system) of the same building with the same hybrid ventilation system simulated with the same model by the same team were two times higher with the set with favourable input data than with the unfavourable ones! The conclusions of that analysis were that, without a clear framework on how to carry out such an analysis (and in particular without a clear definition of the input data), it is possible to obtain very different conclusions about the performances of innovative systems (see § 3.6 for further details).

Now that all 25 Member States have to adopt an EPB regulation, it is clear that the issue of the assessment of the performances of innovative systems becomes really challenging. If no correct framework is developed, the national implementation of the EPBD may become a major barrier for the market uptake of innovative systems. Therefore, this topic was intensively discussed in the RESHYVENT project[2].

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[1] Glossary: EP = Energy Performance, EPB = Energy Performance of Buildings, EPBD = Energy Performance of Building Directive.

[2] Remark: this work was originally not planned in the framework of the RESHYVENT project, but appeared to be necessary during the project.

This report aims to present some results of that work. On the one hand, it will highlight the need for the development of a coherent approach, based on a mixture of European measures and national actions. On the other hand, it will present a generic (but not operational) proposal for practical approach for simulating the performances of such systems.

This report addresses only the aspect relative to the simulation of the performance of advanced ventilation system. It focuses only on the aspects that can be treated at international level by addressing items as the general philosophy or the work on input data. The link between these simulations and the way to integrate these results within the national regulations is not addressed in this report. For the moment, this link is very country dependant and a specific study (study of equivalence) has to be done in each case for each country.

Part 1: General considerations related to the assessment of innovative systems in the framework of EPBD

2 GENERAL CONTEXT: THE EPBD

2.1 THE ENERGY PERFORMANCE OF BUILDING DIRECTIVE

One of the biggest challenges the World is facing in this early stage of the 21st Century is ***to reduce the energy consumption***, especially fossil and nuclear energy consumption. There are several reasons for doing so, e.g.:

1. ***to preserve the environment,*** by reducing greenhouse gases emissions (i.e. CO_2) and nuclear waste production,
2. and therefore, ***to comply with our international obligations*** (Kyoto Protocol),
3. ***to influence the global energy market and hence the security of energy supply*** in the medium and long term,
4. ***to reduce sources of potential international conflicts***.

The building sector is an important player, as it is the main energy consumer in Europe. Indeed, 40% of the energy consumption is to be found in residential and tertiary sectors (mainly buildings), against 31% for transport and 29% for industry ([3]). Therefore, it is not surprising that, according to the Green Paper of the European Commission, energy savings in buildings has to be one of the priorities for future action. The Directive on the Energy Performance of Buildings (EPBD) is in line with this objective.

According to its first article, this Directive lays down requirements as regards:

a. the general framework for a methodology of calculation of the integrated energy performance of buildings (this methodology includes, in addition to thermal insulation, other factors that play an increasingly important role such as ventilation, heating and air-conditioning installations, hot water supply, lighting, passive solar system and solar protection, indoor climatic conditions, design of the building, as well as use of renewable energy sources…);

b. the application of minimum requirements on the energy performance of new buildings;

c. the application of minimum requirements on the energy performance of large existing buildings that are subject to major renovation;

d. energy certification of buildings; and

e. regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

The Directive has been published on 4 January 2003 and must be implemented within three years after its publication, which is a very short delay[3].

[3] In the case a Member State can prove that the number of available inspectors will not be sufficient, a delay of three years can be accorded for what concerns the certification and the checks of boilers and air conditioning systems.

In accordance with the principles of subsidiarity, the EPBD only establish a general framework for the assessment of the energy performance of buildings and for their certification, but the detailed implementation is left to the 25 Member States[4]. In particular, the EPBD does not impose minimum energy performance for buildings: these targets have to be specified by the Member States. This allows each Member State to choose how to meet the Kyoto and EPBD requirements according to its particular situation. It must be noticed that the proposed "Directive on energy end-use efficiency and energy services"[5] may go a step further and may impose minimum energy targets for the member states.

2.2 IMPACT OF ENERGY REGULATIONS ON THE MARKET

There are many examples that show that energy regulations can have a strong impact on the market. Some are summarised below.

The introduction of the mandatory use of low-e glazing in April 2002 in England and Wales for all new or refurbished windows has been translated in a dramatic increase of the sales of this kind of glazing as illustrated on Figure 1. The market for low-e glazing is now nearly equal to 100% of the sold glazing. The same tendencies have been observed in Germany where a similar regulation has been introduced.

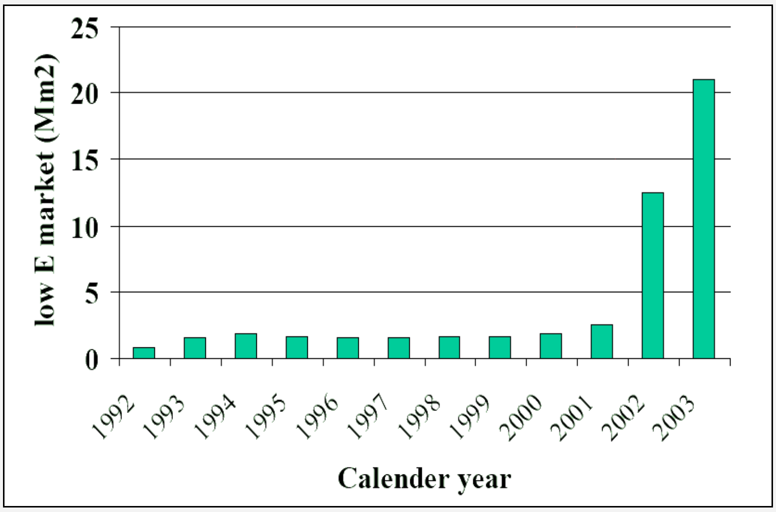


Figure 1: Impact of the introduction of the mandatory use of low-e glazing in April 2002 in England on the evolution of the sales of this glazing (source Pilkington™)

Example 1: Impact of mandatory use of low-e glazing in England and Wales

[4] The energy performance of buildings should be calculated on the basis of a methodology which may even be differentiated at regional level.

[5] See: http://www.europa.eu.int/comm/energy/demand/legislation/library_en.htm.

The basis calculation procedure of the French EPB regulation takes humidity-controlled ventilation devices into account. This is very specific to France and this kind of technology is generally not considered in the basis calculation procedure of the energy regulations in other countries. Millions of such ventilation devices have been sold in France. Although this kind of technology can insure a good indoor air quality with substantial energy savings by reducing the average airflows, there's almost no developed market outside France because of the lack of stimuli found into national building regulations.

Figure 2: Examples of humidity-controlled ventilation devices mainly sold in France

This example illustrate that technologies not covered by the energy regulations are de facto nearly outside the market.

Example 2: Impact of the French EPB regulation (RT2000) on humidity controlled ventilation devices

Energy performance regulations can also have impact on a broader scale. An energy performance regulation is in force in The Netherlands since 1995. The building projects in The Netherlands are characterised by large projects of several hundred of houses. The adoption of the EPB regulation has had an impact even at the urbanism level since new areas of cities have been created adopting the best possible orientation in order to use to a maximum the passive solar energy.

Example 3: Impact of Dutch EPB regulation on the urbanism

2.3 IS THE EUROPEAN UNION CREATING MARKET BARRIERS BY IMPOSING ENERGY PERFORMANCE REGULATIONS?

An Energy performance regulation should allow a comparison between the different technologies integrated into a building. It then becomes possible to compare the impact of several design choices onto the conventional final energy consumption of the building. Options as additional thermal insulation can be compared with the choice of a more efficient boiler, with more efficient lighting, with the use of solar shadings or with the placement of PV-cells.

By doing so, the EPB regulation stimulates the most efficient energy technologies without specifying which one the market has to choose. The market will select the technologies presenting the most interesting 'Improvement in E-level / Investment cost' ratio (see Figure 3).

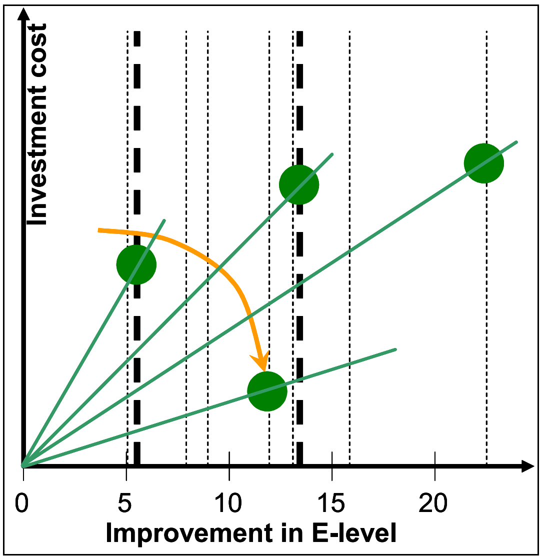


Figure 3: Comparison of different design choices in a building – selection based on the most interesting 'Improvement in E-level / Investment cost' ratio

However, this is only valid if all technologies can be assessed by the calculation procedure. If some technologies cannot be assessed, it will not be possible to compare them with all the other covered technologies. The investment cost is generally known, the improvement in E-level cannot be estimated (see Figure 4). All the technologies situated on the vertical red axis are in this situation. Even if the considered technology is much better than all the other ones, it will not be possible to prove it with the compulsory calculation procedure. This technology is de facto out of the market.

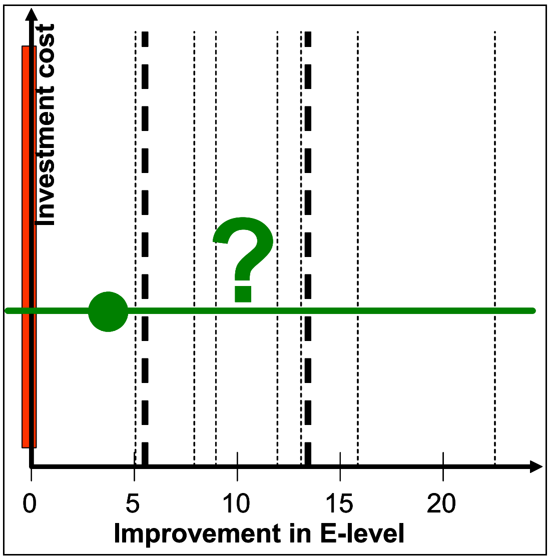


Figure 4: Example of technology not covered by the calculation procedure

Standard calculation methods cannot cover all the technologies. Innovation can go further than what is foreseen in the standard procedures. An "escape route" has to be foreseen to allow the not covered technologies to enter the competition by allowing the official calculation of their impact on the energy consumption of the buildings. It is the so-called ***"Principle of Equivalence"***.

As an example, in the Flemish legislation, specific articles are included for allowing the assessment of innovative concepts:

- In the Flemish Decree regarding the energy performance of buildings ([4]) and adopted by the Flemish Parliament in April 2004, article 7 specifies: “The Flemish Government can decide that buildings which make use of innovative building concepts or technologies, may apply an alternative calculation method’.
- In the related Execution order by the Flemish government, article 22 specifies: ‘Buildings which make use of innovative building concepts or technologies, and which cannot be evaluated by the calculation procedures provided in the annexes of this execution order, can be judged by means of alternative methods, as far as can be shown that the performance levels of these buildings are at least equivalent with the requirements in this execution order.’

By introducing mandatory EPB regulation in all Member States, the EU increases the market for efficient energy technologies. It indirectly also creates major market barriers to technologies not covered by the calculation procedures by forcing them to follow an escape route that is not yet available in most of the EU countries.

2.4 Needs for international collaboration around the EPBD

A single European EPB calculation procedure could have been an interesting option for Member States, industry and end-users. However, this is not the case and this situation is not expected in a short or a middle term. As expressed by the SAVE ENPER-TEBUC project ([5] [6] [9]):

> *The **reality** is that different Member States have different EP regulations, in different states of development and sometimes based on different principle choices.*
>
> *The **reality** is also that there exists a wealth of standardised calculation methods from CEN, published or under development, which were however not developed for the purpose of (common) EP regulations and therefore show inconsistencies and gaps when these are applied in the context of EP regulations.*
>
> ***Fact** is also that a number of CEN Product Standards are in the pipeline or already published, giving component data, including on energy related properties, but – again– not fully compatible with the needs from EP regulations.*
>
> *Finally, the **fact** is also that the Energy Performance in Buildings Directive requires that in each Member State EP regulations must have been implemented before the end of 2005 and that there clearly is not enough time to come to a unique European procedure.*

Despite these facts, international collaboration around the EPBD is required.

2.4.1 Member States needs for international collaboration around the EPBD

To stress the Member States needs for international collaboration around the EPBD, it might be useful to compare this situation with the one created with the publication of the Construction Product Directive (CPD).

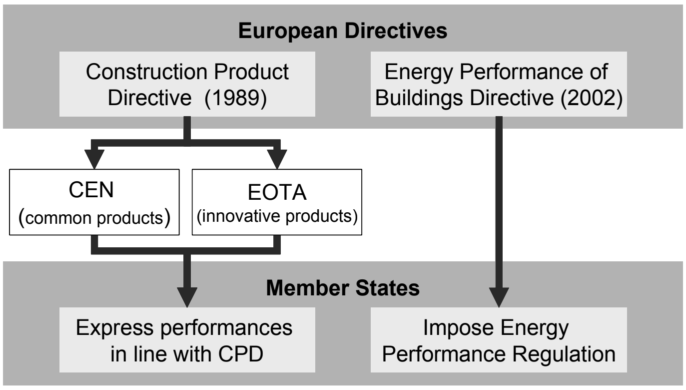


Figure 5: Comparison between the implementation of the CPD and the EPBD

The CPD ([10]) aims to create an open platform for performance assessment of building products. The development of practical assessment procedures is in the hands of two European organisations: the European Standardisation Organisation (Comité Européen de Normalisation, CEN) for what concerns standard products and the European Organisation for Technical Approval (EOTA) for what concerns innovative products. The role of the Member States in the development of the procedures is limited. Consequently, the procedures will be the same in every Member States.

The situation created by the EPBD is different in the sense that there is no European organisation in charge of developing a methodology for the assessment of the Energy Performance of Buildings: this in the only responsibility of the Member States[6].

All Member States are expected to face the same kind of problems or challenges when developing the procedures and the legislation. Some of these challenges are presented in Figure 6. Therefore, international collaboration helps the Member States to solve these challenges, by learning from other experiences.

[6] A second difference between the implementation of both directives is the timing. For the CPD, the implementation was intended to be fully implemented within 30 months of its notification. However, as the procedures were not made available by CEN, the implementation is still going on 15 years later!. The Member States can not be made responsible for the delay. Oppositely, Member States will be held responsible for any delay that would occur with the implementation of the EPBD.

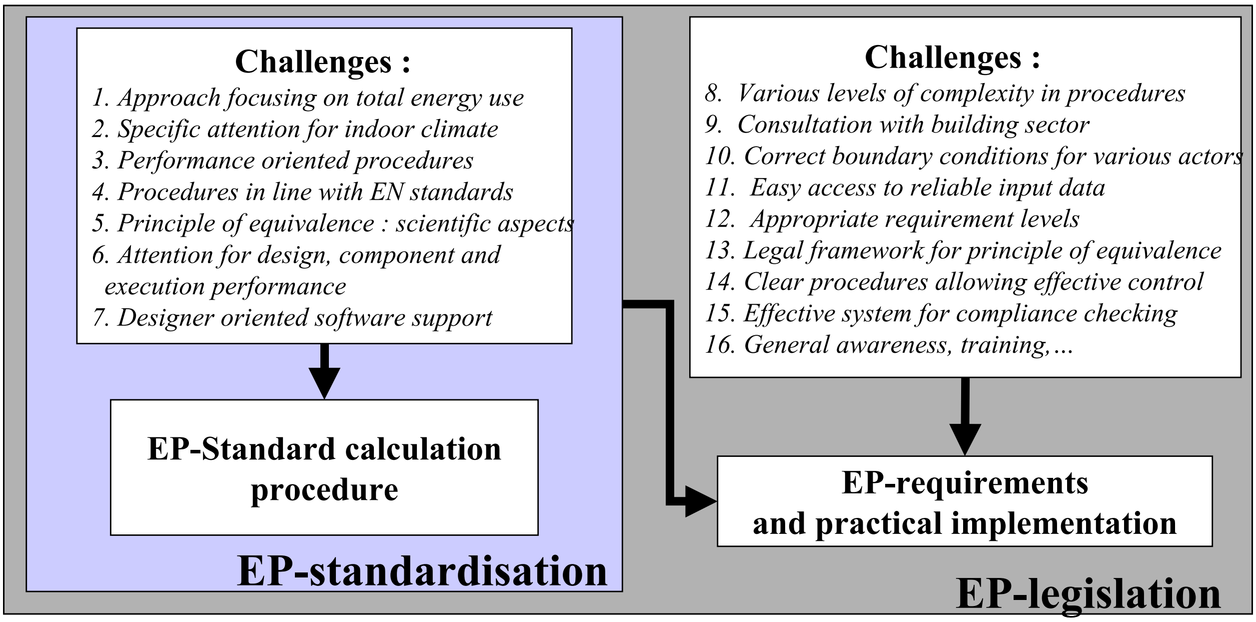


Figure 6: Challenges for an EP approach and interaction between EP standardisation and legislation (source: [11])

It must be stressed that the EPB regulations should be based on CEN standards. Unfortunately, most of CEN standards do not focus on the needs of energy performance regulations. Moreover, many procedures for various important aspects are not covered at the moment. As the Member States have no time to wait with the adoption of their national regulations until CEN has made all the required procedures available, they have to develop national methods, often with major limitations and with a wide dispersion, creating barriers for CEN and EOTA procedures in a later stage. This situation represents major disadvantages for the Member States and for the industry and creates major new barriers for innovation.

2.4.2 Industry needs for international collaboration around the EPBD

One of the major goals of the EU is to promote an European free market and to facilitate the free circulation of goods. The European standardisation is a tool to reach this objective. The national standards should be replaced by European standards, so that the products can be evaluated anywhere in EU with an identical procedure and sold anywhere else.

It is important that the national EP Regulations do not introduce new barriers, due to the fact that they are based on new national procedures. For this purpose, it would have been nice to have a single European EPB calculation procedure developed by e.g. CEN; only the requirements would have been decided at national (or regional) level.

For various reasons, it is not the case. The situation is now that a technology can be evaluated as more efficient than another in one Member State, but as less efficient in another country. This situation is already damageable for existing technologies, but would be even more damageable for new technologies not yet covered by the standard EPB calculation procedures, as we will see in chapter 3. In order to minimise this risk, international collaboration is requested.

2.4.3 End user needs for international collaboration around the EPBD

For an architect or a consulting engineer who works always in the same country, a common European EPB calculation procedure is probably less important. It would however be preferable for international companies and architects/consulting engineer working in different countries. Moreover, it would help the diffusion of products and knowledge across EU.

2.5 OBJECTIVES OF THIS REPORT

The major aims of this document is on the one hand to highlight the need for the development of a coherent approach, based on a mixture of European measures and national actions, and on the other hand to present some methodological considerations to integrate into a practical approach (not fully developed into this report).

We ***could*** have started right away with the drafting of a common methodology. But we did not. Simply because we believe that this could easily become a Babylon's tower: an impressive building, but cemented with a mixture of misunderstandings.

This report aims "only" to produce, as a first step, an outline for the assessment of innovative technologies, and more specifically about advanced ventilation systems.

A practical example is presented into this report. This example aims to illustrate the possibilities and challenges of a methodology and the type of information which can be expected. It must be stressed that this example is NOT MORE THAN an example.

3 HANDLING INNOVATIVE SYSTEMS IN THE FRAMEWORK OF THE ENERGY PERFORMANCE OF BUILDING REGULATIONS

3.1 DEFINITION OF INNOVATIVE TECHNOLOGIES (IN THE CURRENT FRAMEWORK) AND TYPICAL EXAMPLES OF SUCH TECHNOLOGIES

In the framework of this report, ‘innovative technologies’ are defined as ‘Technologies:

- that in most cases give a better performance in terms of the energy performance of buildings than the common technologies and,
- whose performance cannot be assessed by the procedure in the Energy Performance calculation method.’

According to the definition mentioned here above, we can say that, in the context of this report a glazing unit with a very low thermal transmittance (e.g. U-value = 0.3 W/m²K) is not an innovative technology if the procedure in the EPB regulation is based on EN 673 [12], because this standard allows the calculation of such U- value.

Oppositely, an electrochromic glazing is an innovative technology, if the EP method foresees no procedure for handling the fact that the properties of this glazing vary with time. This will probably be the case because there is currently no CEN standard to estimate the energy performances of such glazing on an annual basis.

Figure 7: Examples of technologies typically not-covered by the basis calculation procedures of energy regulations
a. Ventilated Double-skin Façades – b. Green roofs
c. Thermal mass activation – d. Ventilation system controlled by presence detection sensor – e. Passive cooling using intensive night ventilation

Other examples of technologies that typically are not covered by EP regulations are (see Figure 7) ventilated double-skin façades, green roofs, thermal mass activation, ventilation system controlled by a presence detection sensors, passive cooling using intensive night ventilation, …

In general, systems with **time variable properties** are not taken into consideration in most EP procedures and have therefore to be considered as innovative technologies in the context of this report.

It is important to note that, according to the above definition, a technology can be considered as innovative in one Member State and not in another. For instance, ventilation systems based on humidity control are integrated in the French basis procedure of EPB regulation; they are therefore not considered in France as innovative systems whereas they will be considered as such in most of the other European countries.

3.2 Needs of the industry related to innovation

The EP regulations developed by in the different Member States (due to the EPBD or prior to it) become more and more driving factors for industry in relation to product development. One of the key questions for industry is:

How can we improve and optimise our products with respect to the performance assessment made in EP regulations?

In order to allow such approach, it is crucial that there is transparency in relation to the assessment methodology. According to the authors, this transparency is lacking for the majority of the innovative systems. This impression is confirmed by several major manufacturers who are active throughout Europe.

As such, the EPB regulation approaches, which in principle should be strong stimuli for product innovation, may become a barrier for innovation.

The needs of industry include:

- **Information in time** about the assessment methodology of innovative systems. Such information should preferably be available at the start of the development of innovative systems. It is unacceptable that industry can only ask for an evaluation once the system is completely developed (unfortunately, this is the present reality).
- **A minimum level of coherence** in the assessment procedures by the different Member States. It is extremely inefficient to be confronted in the different countries with completely different assessment schemes.
- **A sufficiently open assessment scheme** which allows optimisation of systems and products.

3.3 CHALLENGES RELATED TO HANDLING INNOVATION IN ENERGY PERFORMANCE REGULATIONS

Figure 6 has shown the challenges that Member States must solve to efficiently implement the EPBD. Two of these challenges clearly deal with the issue of innovation and are briefly discussed below.

Challenge 5: Open platform for innovation: coherent scientific philosophy with respect to the Principle of Equivalence

It is crucial that the whole EP philosophy takes into consideration the so-called Principle of Equivalence from the beginning. It means in practice that one should have a correct philosophy for allowing in a later phase a correct assessment of the Principle of Equivalence.

Moreover, and this is crucial in relation to the RESHYVENT project, we believe that it becomes less and less evident to develop such philosophy within a purely national context since innovative systems are/will be used throughout Europe.

Challenge 13: Legal framework for the application of the Principle of Equivalence

Given the importance of the Principle of Equivalence as a measure for correctly assessing innovative approaches, a legal framework for proof of compliance is needed. The authors believe that it is not realistic to expect from a communal civil servant to correctly assess such approaches (as it is the case in The Netherlands) and, therefore, an assessment procedure at a higher level is required.

It is important to stress that these two challenges are of a completely different character:

1. The first one is mainly a scientific-technical issue: the availability of an assessment method which allows to correctly compare various innovative systems whereby it is crucial that there is a consistent treatment of various technologies. This may seem evident but we believe it is not so simple. This second part of this report is directly related to this challenge.
2. The second one is mainly an administrative issue: there should be clear procedures for formally assessing (and approving) studies made in relation to the Principle of Equivalence.

3.4 THE CONCEPTS OF THE PRINCIPLE OF EQUIVALENCE IN THE DUTCH LEGAL FRAMEWORK

The Netherlands have a long experience of this Principle of Equivalence (PoE). Its application is foreseen in the Dutch Building Decree (see Figure 8). Note that, in The Netherlands, the PoE may be applied for all aspects related to construction work, and not only those related to EPB.

§ 1.3. Principle of Equivalence

Article 1.5

The prescription in the second until the sixth chapter that has to be applied in order to satisfy to a requirement concerning a construction or part of it, does not have to be satisfied, if, differently than by applying this prescription, this construction or the concerned part offers at least the same safety, protection of health, usability, energy savings and protection of the environment, as it has been aimed at with the concerned prescription.

Figure 8: Principle of Equivalence as defined in the Dutch building decree (Free translation of the "Bouwbesluit")

Consequently, in the Dutch legal framework, the PoE can be applied if:

- the **test methods** or the **calculation procedures** are not suitable (see Example 4 below) ,
- the **requirements** are not suitable (see Example 5 below).

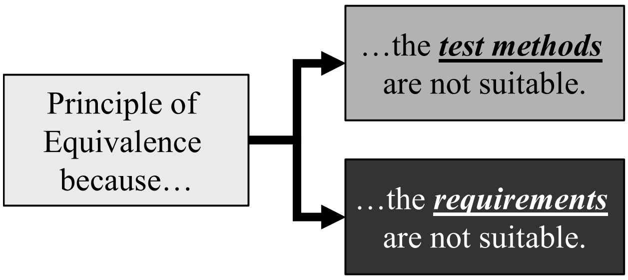


Figure 9: Different levels of application of the PoE: test method vs. requirements

Application of the PoE because the calculation procedure is not suitable: example of an innovative ventilation system

In the Dutch EPB regulation, the ventilation and infiltration have to be specified according to a generic equation which is independent of the ventilation system:

$q_v = 0.47 A_g + 0.13 q_{v10}$

where: q_{v10} is the airflow rate for ventilation and infiltration of the heating zone in the building [dm^3/s], A_g is the useable ground floor area of the heating zone in the building [m^2] and q_{v10} is the air leakage of the building [dm^3/s].

If the control strategy of a hybrid ventilation system is demand controlled, the yearly average airflow could be less than what is supposed by the above equation. In that case, a (good) Principle of Equivalence report would estimate this yearly average airflow under the same conditions than the reference airflow (which means an equal or better IAQ, in the same building, under the same climatic conditions, but with the hybrid ventilation instead of a classical system).

For instance, the demand controlled system developed by ALUSTA™, (Vent-O-System™)

can use the following equation instead of the previous one:

- in case it is applied as a pre-programmed time-controlled system:
  $q_v = 0.30\ A_g + 0.12\ q_{v10}$
- in case it is applied as a CO_2-controlled system:
  $q_v = 0.236\ A_g + 0.0087\ q_{v10} + 0.0009\ q_{v10}^2$

These equations have been determined by a PoE analysis, carried out by TNO. Although the calculations have been done for a dwelling with an occupancy of 4 people, the PoE analysis is valid for any residential building, as the equation of the standard procedures has also been determined for a dwelling with an occupancy of 4 people.

Example 4: Application of the PoE because the calculation procedure is not suitable

Application of the PoE because the requirement is not suitable: example of balanced ventilation system in large residential buildings

In The Netherlands, the Building Decree requires a nominal airflow rate of 0.9 $dm^3/s.m^2$. This airflow comes from the following assumptions:

- CO_2 production per person: 18 l/h or ≅ 35600 mg/h
- acceptable ΔCO_2 = 800 ppm ≅ 1440 mg/m^3
- available surface per person = 7.8 m^2/person

➔ $q_{v,sup}$ = 35600 mg/h / 1440 mg/m^3 / 7.8 m^2.person ≅ 3.2 $m^3/h.m^2$ ≅ 0.9 $dm^3/s.m^2$

However, in large dwellings with low occupancy, this can be a lot too much. For instance, a large villa of 197 m^2 can be occupied by 2 people. The nominal airflow rate is 197*0.9 = 177 dm^3/s, which can be reduced to 156 dm^3/s thanks to allowed recirculation. This corresponds to a nominal occupancy of 22 persons! As the basic aim of the regulations is not to provide 7 dm^3/s.person but a good IAQ, the PoE was used by TNO to find airflows that give the same IAQ for an occupancy of 6 persons. The calculations were based on the same methodology that was used to determine the relationship given in the standard calculation procedure.

It was found that a total outside air supply of 63 dm^3/s was sufficient to maintain the same level of IAQ.

This PoE analysis is only valid for large dwellings with:

- a balanced ventilation system,
- a maximum floor area of 200 m^2,
- an occupancy level equal or lower that 6 persons,
- an air tightness varying from q_{v10} = 30 to 80 dm^3/s (corresponding to n_{50} = 1 to 3 h^{-1}),
- an effective outside air supply of 7 dm^3/s.person in bedrooms during occupancy.

The municipality is (theoretically) in charge to verify this.

Example 5: Application of the PoE because the requirement is not suitable

Moreover, when the PoE is applied due to the fact that the test methods/calculation procedures are not suitable, it is important to distinguish between two levels. A PoE analysis can be carried out for an innovative system and/or for a specific building.

- An example of application of the PoE for an innovative system was already given in Example 4 above.
- An example of application of the PoE for a specific building was the Dutch school that was analysed in the framework of the HYBVENT project (see Example 6 below).

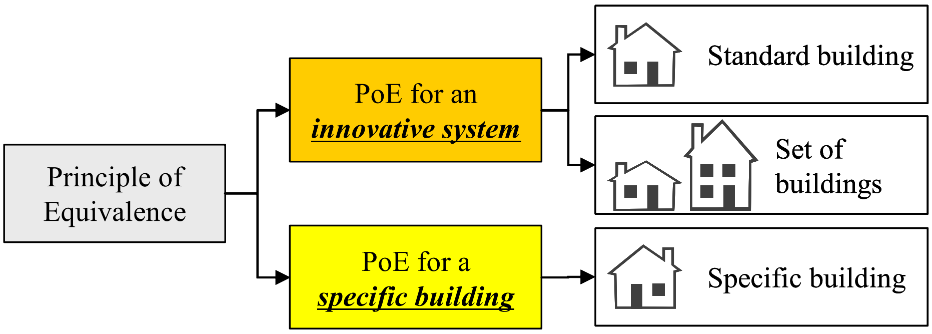
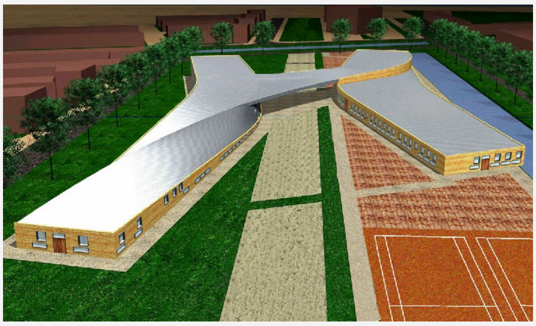


Figure 10: Different levels of application of the PoE: system vs. building

Application of the PoE to a specific building: example from HYBVENT: the Dutch school "Waterland" at Leidschenveen
The building is equipped with a hybrid ventilation system. The requirements of the property developer for this building were to build a school that has 15% lower energy consumption then required in the Building Decree. The building has a gross floor area of approx. 5000 m^2 over 1-2 floors and is divided in three schools and a day nursery. Figure 11 gives an artist impression of the building.  ***Figure 11: School building Waterland at Leidschenveen*** As the standard calculation procedure was not able to assess the energy performance of the hybrid ventilation system, it was necessary to apply the PoE. The methodology of the PoE study was to compare the performance of the hybrid system with the performance of a system with a natural air supply and a mechanical exhaust. Firstly, an EPC calculation was carried out for the school building equipped with a mechanical exhaust. According to these calculations, the EP* level was found to be 0.98, which meets the requirements of the Building Decree.

Secondly, computer simulations have been carried out with the object oriented simulation model 20-SIM. In this model, a multi-zone ventilation model has been coupled to a thermal model. The results of the simulations of the hybrid ventilation system have been compared to those of the mechanical exhaust system. The proportional alterations of the heating energy and running hours of the fans have been applied to the known results of the energy performance calculation of a mechanical exhaust system. The simulation results for both ventilation systems show that the heating energy consumption is reduced by 24.3% and the running hours of the fans are reduced by 77.9%. Consequently, the EP* level for the hybrid ventilation system is estimated to 0.80, which corresponds to a saving of 18% of the primary energy consumption, compared to a mechanical exhaust system.

Consumption	Prim. energy consumption [MJ]		
	Mech. ventilation	Difference	Hybrid ventilation
(1) Heating	2 441 597	-24.3 [%]	1 848 289
(2) Fans	228 000	-77.9 [%]	50 388
(3) Lighting	1 229 738		1 229 738
(4) Pumps	67 987		67 987
(5) DHW	157 397		157 397
(6) $Q_{pres;total}$	Σ(1→5) = 4 124 719		3 353 799
(7) $Q_{pres;adm}$	4 193 046		4 193 046
(8) EP^*	(6)/(7) = **0.98 [-]**		**0.80 [-]**

Table 1: Calculation of equivalent EP^* coefficient.

Remark: as the building has more than one function, the Building Decree states that the calculated characteristic energy consumption should be equal or less than the admissible characteristic energy consumption; this ratio is the EP* level given here.

Example 6: Application of the PoE to a specific building

This example will be analysed more in details in § 3.6.

Some important facts about the application of the Principle of Equivalence in The Netherlands have to be highlighted.

- The PoE analysis has to be evaluated by the municipality where the construction work will take place. Of course, all municipalities do not have the same competences to evaluate such reports. Consequently, the same building with the same innovative system could possibly be accepted in one municipality and rejected in another one.
- Anyone can make a PoE analysis (for so far the report is accepted by the municipality).
- The regulation does not specify anything about how a PoE analysis must be carried out, and especially about the reliability of the assumptions that have to be done.

Consequently, the PoE can be considered as very open, but also as fuzzy.

3.5 THE PRINCIPLE OF EQUIVALENCE IN THE FRENCH LEGAL FRAMEWORK

Two years before the publication of the EPBD, France had already introduced an EPB regulation: the so-called "Règlement Thermique RT2000".

The controlled systems are evaluated with a special agreement ("Avis Technique") in order to assess their performances (IAQ and energy losses). Actually only humidity controlled system are evaluated but the same approach can be used with hybrid systems.

The analysis is conducted by CSTB using both laboratory tests (aeraulic characteristics of the component) and the computer code SIREN developed by CSTB (it is theoretically possible to use another code with exactly the same assumptions but in practice only SIREN is used). The results of the analysis are laid out to a national commission ("Commission des Avis Techniques") that delivers the "Avis Technique".

The simulations are carried in order:

1) to verify than the building and the IAQ are preserved.

IAQ in based on the cumulative CO_2 concentration above 2000 ppm (incl. 350 ppm outdoor) in the living room and the bedrooms, when the occupants are present during the heating season. This cumulative CO_2 concentration may not exceed 500.000 ppm.hours.

Building preservation is based on the number of hours of possible condensation in main rooms and bedrooms.

These values have been laid out by comparison with a fan assisted exhaust ventilation system, whose constant flows are in accordance with hygienic requirements ("arrête du 24 mars 1982 modifié")

2) to determine the average airflow rate through all the year, and the equivalent air inlets apertures, both to be introduced in the RT2000 Th C calculations. The average airflow rate is the one that give the same heat losses during the heating season (seven month) and is be calculated by:

$$Q_{avg} = \frac{\int 0.34 \times Q(t) \times (T_i - T_e(t)) \times dt}{\int 0.34 \times (T_i - T_e(t)) \times dt} \qquad \text{(only when Te(t) < 15 °C)}$$

Where:	Q(t) is the instantaneous ventilation flow rate	[m3/h]
	T_i is the internal temperature (assumed as constant: 19 °C)	[°C]
	T_e is the external temperature	[°C]
	0.34 is the specific heat of air	[Wh/m³.K]

3.6 THE IMPACT OF THE ASSUMPTIONS, ILLUSTRED BY THE "EVIL APPROACH"

The performance assessment of advanced ventilation systems in the framework of energy and IAQ regulations was already analysed in the framework of the HYBVENT project (see [13]).

For this purpose, the performance assessment of the hybrid ventilation system of the Dutch school (see Example 6 above) was analysed more in detail. Especially, the importance of the assumptions was highlighted by making three PoE analyses, with different sets of assumptions.

The set of assumptions included the following parameters:

- Pressure distribution,
- Occupancy pattern,
- CO_2 production,
- Acceptable IAQ (CO_2),
- Night temperature control,
- Internal heat production.

For each parameter, three values were fixed. All these values could be defended, as they were found in reliable literature.

Firstly, simulations have been carried out by changing parameters one by one. The results are given in Table 2.

Parameter	**Reference**	**EP^* [-]**	**Variant 1**	**EP^* [-]**	**Variant 2**	**EP^* [-]**
Wind pressure	semi-sheltered	0.80	sheltered	0.79	exposed	0.81
Occupancy	medium	0.80	low	0.75	high	0.81
CO_2 max	1300 ppm	0.80	1500 ppm	0.78	1000 ppm	0.83
CO_2 production	18 l/h	0.80	15 l/h	0.78	23 l/h	0.83
Night temp. setback	6 °C	0.80	3 °C	0.81	9 °C	0.80
Internal heat	41 W/m^2	0.80	36 W/m^2	0.81	51 W/m^2	0.80

Table 2: Results of EP^* depending on different values for each parameter.

Based on these results, the various values have been combined to obtain favourable set of assumptions (the "evil" approach) and a conservative one (the "decent" approach). The simulation results for the decent approach tend to the performance of a mechanical ventilation system. The results of the evil approach point to a natural ventilation system.

The results of these extremes have been compared to the performance of a mechanical ventilation system, with the same starting points. Figure 7 shows the results of the comparison.

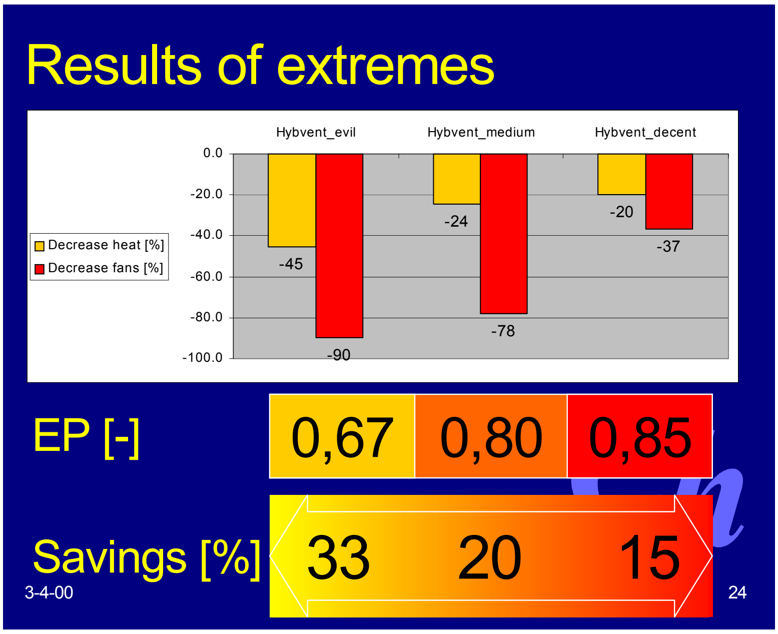


Figure 12: Final results of extreme variants (source: [13])

Depending on the approach, the reduction of the heating energy varies between 20 to 45%. The reduction of the fan energy varies between 37 to 90%. This leads to an EP* of 0.67 to 0.85, or a calculated total energy saving between 15 to 33%. In other words, with the "evil approach", the energy savings are two times higher than with the "decent" approach.

The client could have great disillusions if the design team present to him the results of the "evil" approach and if the actual performances are closer to the one of the "decent" approach. But in any cases, the building and its hybrid ventilation system must be accepted by the authorities (for so far the methodology of the PoE analysis and the simulation model are trusted) as, in this specific case, all three sets give an EP* level which is below the allowed level (1.00). However, it's easy to imagine that in other PoE analysis, it possible to have an "evil" approach below the allowed limit, whereas a "decent" approach or even a "medium" approach would be above the limit allowed by the authorities.

4 GENERAL METHODOLOGICAL CONSIDERATIONS RELATED TO THE ASSESMENT OF INNOVATIVE SYSTEMS OR TECHNOLOGIES IN THE FRAMEWORK OF EPB REGULATIONS

4.1 CHARACTERISTICS OF AN IDEAL ASSESSMENT PROCEDURE FOR INNOVATIVE SYSTEMS OR TECHNOLOGIES

Figure 13 presents some of the characteristics that an **ideal** assessment procedure for innovative systems or technologies should have:

- It should be **available now**. The innovation is already put in danger if the industries are not able to know how the products they have in mind will be evaluated when the EP regulations will be in force.
- It should be **"transparent"**, in the sense that it is not too difficult to obtain a good understanding of the philosophy of the assessment approach, of the parameters of influence and of the possibilities for optimisation.
- It should be **reliable**; the "evil approach" should be prevented.
- Consequently, the parameters that are known to influence the performances of the systems to be analysed should be identified and **input data should be made available by the authorities**. (In the case of the Dutch school for instance, some of the assumptions should clearly not have been let to the choice of the designer, as maximum allowed CO_2 concentration, CO_2 production rate…)
- Although not evident but essential on the long term: the concept should be **open to new developments**, in the sense that it should allow the assessment of totally new developments. New developments might also require new input data, which should be made available by the authorities, within an acceptable period.

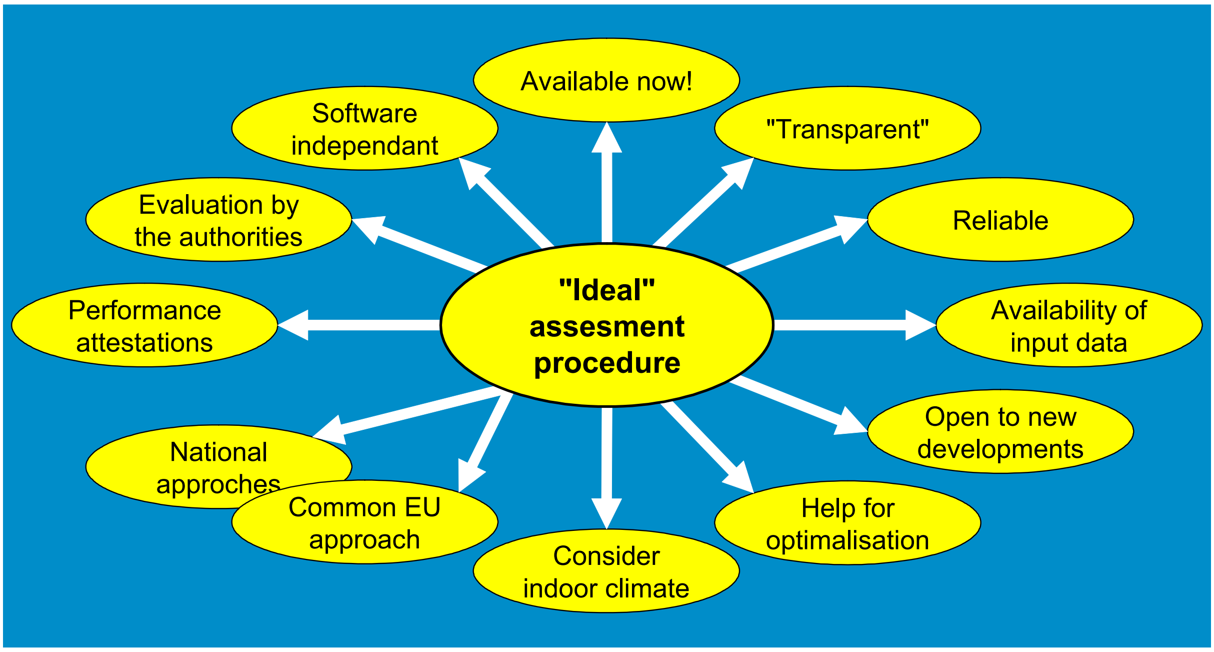


Figure 13: Ideal assessment procedure for innovative systems

- It must allow **optimisation studies**; the industries should be able to easily see the impact of any change to their systems on the calculated performance.
- It should pay attention not only to energy, but also to **indoor climate**, as expressed in article 4 of the EPBD (as well in many national regulations). In case of an innovative ventilation system, the IAQ must be guaranteed. The EPB regulations should allow the use more energy for ventilation, if this increase the IAQ and/or the thermal comfort (as ventilation might reduce (or increase) the risk of overheating), as in this to some extent the case in the Flemish/Belgian EPB regulation. This aspect is further discussed in § 4.2.
- As explained in § 4.3, it should be a mixture of **international and national approaches**.
- Aspects related to the validity of the **performance certification** should be clarified (see § 4.4).
- The result of the performance assessment should preferably **not depend on the software** used for the evaluation…
- …

It is important to keep in mind that the characteristics mentioned above are those that an "ideal" procedure should have. It might be difficult to implement some of them, in the short-term (as e.g. availability of input data), or even in the long term (as e.g. software independent).

4.2 ATTENTION FOR INDOOR CLIMATE

4.2.1 Framework for handling periods of lower/better IAQ and/or thermal comfort conditions

The majority of the systems are not able to keep the indoor air quality and/or the temperature at a fixed level. At certain moments of time, the indoor climate will be better than the target values whereas less good during other periods. Innovative (hybrid) ventilation systems offer attractive opportunities for such improvements, in particular if compared with natural ventilation.

In order to quantity this advantage, it is important that the IAQ or thermal comfort level is taken into account during the evaluation of the performances of the system, as it the case in the Netherlands and in France (see § 3.5).

4.2.2 No penalty / rewarding for indoor climate improvements

Certain systems may focus on the improvement of indoor climate conditions. An example is the addition of a CO or smoke sensor in a living room. It is clear that the use of such system will result in a higher air flow rate and higher energy use. If an EPB evaluation scheme evaluates such systems as energetically less performing than systems without such detector, it is clear that there is a major barrier for applying such systems.

To our opinion, a correct EPB scheme should explicitly take into account the IAQ criteria and give a benefit to such systems. This requires that e.g. various types of air pollution sources are taken into consideration.

4.2.3 No penalty / rewarding for handling unexpected occupation

The majority of the systems are dimensioned for the nominal occupancy, e.g. 1 person for a single office. In case of higher occupancies, such systems will give a lower IAQ level. However, there might be systems which are able to handle such overcapacity in an intelligent way. It seems to be important that an EPB procedure is able to handle this kind of aspects.

4.2.4 Summer comfort

Hybrid ventilation systems can also contribute to better thermal comfort conditions in summer. An EPR procedure can/should allow to pay attention to the thermal comfort in summer (as stipulated by the EPBD).

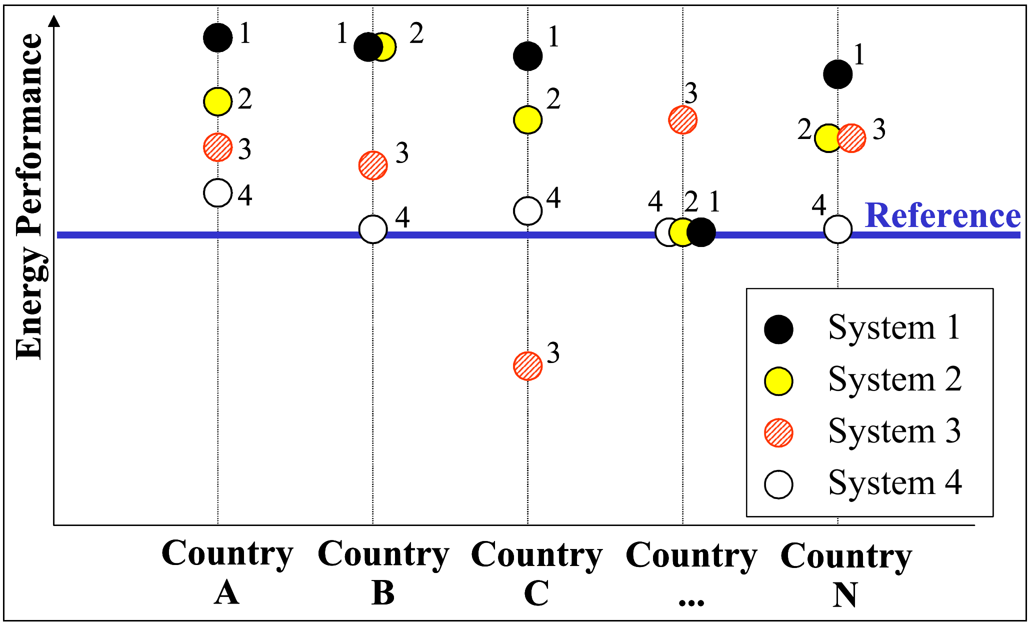
4.3 MIXTURE OF INTERNATIONAL AND NATIONAL APPROACHES

4.3.1 Reasons for having a international approach

In general, the development of an assessment method of the energy performance of buildings is a complex issue and not evident to be handled in a correct and efficient way by each Member State. This is one of the reasons why there are at present a substantial attention and investment by the European Commission in the development of missing CEN standards for the implementation of the Energy Performance of Buildings Directive.

The situation is even more complex for innovative systems. Due to their nature, it is clear that CEN work is not the most evident path for developing assessment procedures. However, this should not prevent international/European collaboration. Without such collaboration, it is for sure that many countries will NOT be able to deliver within reasonable deadlines the required assessment procedures.

However, this does not necessarily mean that a unique assessment method is the goal. At present and even within the next 5 years, it seems unrealistic to envisage such unique assessment method and this for a variety of reasons. We believe that the optimal short to medium term solution is an intelligent mixture of international and national activities.



Country A	• Systems are ranked 1 – 2 –3 – 4 • All systems have a better energy performance than the reference system
Country B	• No advantage to use system 4 • System 1 and 2 have identical performances
Country C	• System 3 has even worse performances than the reference system
Country …	• Only system 3 has better performances than the reference system
…	…

Figure 14: Ranking of different ventilation systems in different countries

4.3.2 Reasons for having national approaches

There are also several reasons for not considering on the short time a purely European/international approach.

Overall national framework for performance assessment

At present and although the overall objectives are comparable, there are major differences in the calculation methods for assessing the energy performance of buildings and/or the air quality. These differences are of different nature, e.g.:

- The different type of ventilation systems (purely natural, mechanical extraction, balanced ventilation, ..) are in various countries not treated in the same way;
- Countries use different weighting factors to convert energy use of different energy vectors (electricity, fuel, natural gas, …) to primary energy consumption (for instance, the conversion factor for electricity depends on the production capabilities);
- Some countries pay in their reference method attention to e.g. building air tightness, ductwork air tightness, energy use for fans, heat recovery, various types of demand controlled ventilation, whereas others don't do this or apply other methods;

- Several countries have already regulations or methodologies for assessing innovative systems:
    - Certain systems are considered by some countries as innovative whereas other countries may consider it as part of the systems which can be covered by the assessment procedures in the legislation.
    - For certain innovative systems, there are already well established national assessment schemes. A typical example is humidity controlled ventilation in France. In such cases, the assessment of innovative ventilation systems probably cannot start from scratch and should (at least partly) take into account the existing assessment schemes.
- …

Climate

There are major differences throughout Europe in relation to the climatic conditions (e.g. temperature, wind, risk of overheating…). This on itself is not a major problem but it requires that the assessment of innovative (ventilation) systems should be done for a whole range of climatic conditions (at national or sub-national level).

Cultural differences

The expectations, the use of ventilation systems, the use of windows … also vary substantially throughout Europe. Such differences should be taken into account in the input data used in the evaluation scheme.

An example is the increased attention paid in especially the Nordic countries for the emission of pollutants by building materials.

Differences in building style and systems' choice

There clearly are major differences in building style throughout Europe. This results in major differences in e.g. thermal insulation level, air tightness, thermal mass, risk of overheating…

Also, major differences are found in relation to the kind of e.g. heating and ventilation systems.

In principle, it should be possible to find a common European framework which takes into account all these differences, whereby the results are country depending.

4.4 PERFORMANCE CERTIFICATIONS

In order to stimulate the use of innovative (hybrid (ventilation)) systems, there must be a platform for the official certification of the performances. At present, it is not very clear which framework has to be used in relation to the EPBD.

In general, performance certifications have a limited duration of validity. A common duration is 3 years. A limited duration is surely needed in this case given the fact that one can expect evolutions in the evaluation concept due to e.g. new systems on the market, identification of additional points of concern… Therefore, a duration of 3 years seems to be the maximum.

5 THE PROBABILISTIC APPROACH

5.1 PRINCIPLE OF PROBABILISTIC APPROACH AND MONTE-CARLO ANALYSIS

The example of the Dutch school has clearly emphasised the importance of the assumptions on the result of a PoE analysis, as well as the need of a clear framework for the assessment of innovative systems.

One of the possibilities to make the assessment more reliable is to use the so-called Probabilistic Approach, which is one of the most widely used techniques for mathematical modelling of stochastic phenomena. It is used in various fields, as stock exchange analysis, risk evaluations, nuclear power safety… The basic idea of this method, applied to building simulations, is given in Figure 15.

Two different designs have to be evaluated by simulation.

- Let us imagine that only one simulation is carried out (*deterministic approach*). In this case, each input variable will be fixed to e.g. its average value. The design that minimises a specific output parameter (as e.g. the energy consumption) will be considered as the best one. In the example illustrated in Figure 15 (left), the best design is design 2.
- However, it is well known that there is some uncertainty on the input values. Using the average value only does not represent the real world with enough accuracy. Therefore, let us now imagine that distributions of possible values are determined for the inputs, including any cross-correlation between them. A number of simulations can be carried out with different values for each input. To evaluate which design is the best one, a new criteria could be taken into consideration: the best design should also have the lowest probability that the output exceeds a limit. By comparing the output distributions of both designs, it is perfectly possible that design 1 appears now to perform better than design 2, as it is the case in Figure 15.

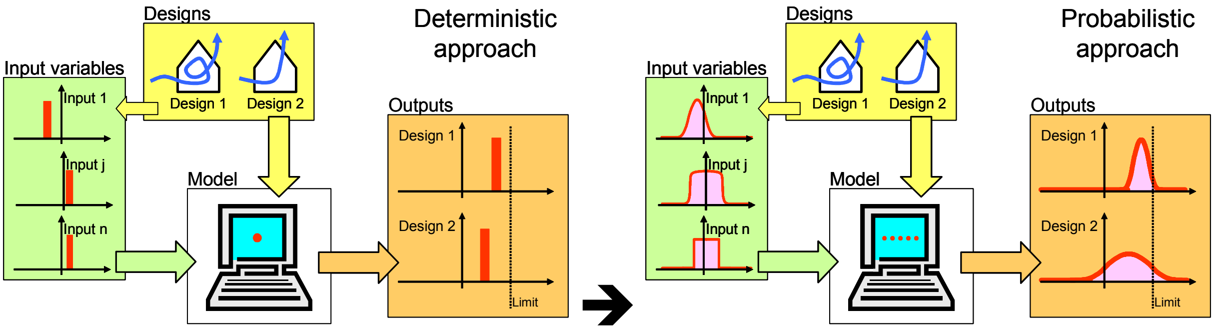


Figure 15: The deterministic approach vs. the probabilistic approach

In order to apply the Probabilistic Approach, some important questions have to be answered.

- Which parameters should be included in the Probabilistic Approach analysis (and consequently, which ones will be considered as deterministic)?
- What are the probability distributions for those parameters (including possible cross-correlations among them)?

- How to generate the values of the various input data? Do they have to be fixed in advance by the authorities or can they be chosen by the person in charge of the PoE analysis?
- How many simulations will be required to reach a sufficient convergence?
- How to use the results to improve the design of the innovative system and/or of the building?
- How to make the link with the simulation results and the EPB regulations?
- …

5.2 Probabilistic Approach versus Sensitivity Analysis

Before we go into more in detail with the Probabilistic Approach, it is important to clearly distinguish between this approach and a more traditional sensitivity analysis.

A first distinction can be made according **to the goal of the analysis**. The aim of a sensitivity analysis is more to see the influence of a specific parameter on the building performances; it is a tool to understand what is important, what does really influence the performances. The Probabilistic Approach is much more a "black box" approach, were the influence of many parameters is addressed, but were the influence of one of them is difficult to identify. In fact, we can imagine a tool for the Probabilistic Approach that could be used to perform sensitivity analysis.

A second distinction can be made according **to the type of parameters and the way they vary**. The term "sensitivity analysis" could be reserved for things for which statistical distribution are available, so that they are known for the building stock, but not for a specific building (ex: building air tightness). The term "Probabilistic Approach" could be reserved for items on which we have no control, and which are really probabilistic (ex: occupancy, possibility to have a party).

5.3 Methodological considerations related to the Probabilistic Approach

5.3.1 Which parameters should be included in the Probabilistic Approach analysis?

This paragraph does not intend to select the parameters to include in the Probabilistic Approach, but to discuss the way the selection must be done.

The experience of the Dutch school has clearly shown that the responsibility for choosing the input data should not be let to the industry, or of the consulting engineer, who will carry out the PoE analysis. It is essential that the list of parameters is fixed in advance by the authorities. In order to help them, it would be useful to have guidelines published by the CEN as a standard or a CEN technical report.

5.3.2 What are the probability distributions for those parameters?

Once again, the probability distribution should not necessarily be fixed by the person who conducts the PoE analysis, as it would be possible for them to select the most suitable distribution (instead of the most suitable single value). Once the list of parameters is fixed, the distribution should be fixed at national level, according to local conditions (e.g. climatic conditions, cultural habits, construction techniques, etc.).

An issue is to determine if the input data distribution/range may or may not include tail-end values that lie outside national building codes. For instance, it is possible that the building code in a Member States requires the building air tightness to be lower than a limit, but that real buildings often do not comply with that regulation. If values of input data that do not comply with building codes are cut-off, then the probabilistic approach will be unrealistically skewed towards too high performance. Alternatively, if a country adopts realistic distribution with values that do not comply with its own regulation, then it is indirectly accepting that leaky buildings can be built. This might be not acceptable for building code regulators; it might even not be legally possible in some countries (like in Portugal).

As it was not possible for the standard EPB calculation procedures to cover all technologies that are not yet discovered, it is not possible for the authorities or for CEN to fix in advance a complete list of parameters that would be relevant in the Probabilistic Approach analysis. It is perfectly possible that an innovative technology requires a new parameter to be included in the Probabilistic Approach (as for instance a ventilation system controlled by the concentration of a specific pollutant not considered by other "traditional" ventilation systems). A legal framework must be set up for this specific case. An option could be that, in this case, the author has to request to the authorities to give him in a short delay the distribution to use. If he does not receive answers in time, he should get the opportunity to use its own distribution.

5.3.3 How to generate the values of the various input data? Do they have to be fixed in advance by the authorities or can they be chosen by the person in charge of the PoE analysis?

Once the characteristics of the distribution to be used for a specific data are fixed by national authorities, the values to be actually used in the Monte-Carlo process have still to be determined. For this purpose, random values should be generated and transformed according to the considered distribution.

Two options are possible: (i) the random numbers could be generated by the author of the PoE analysis or, (ii) by the authorities. In case (i), it could be possible for the author of the PoE analysis to remove simulation results that would be extremely unfavourable, as long as the distribution of input data seems to respect the distribution fixed by the authorities. For this reason, it seems preferable that the sets of input data to use are fixed in advance by the authorities, even if it might be a complex task.

5.3.4 How many simulations will be required to reach a sufficient convergence?

The Monte-Carlo process could be stopped after a fixed number of simulations or after that a certain convergence is reached (or after a combination of those two criteria). Of course, if the input data are given by the authorities, the number of data available should be in line with the requested number of simulations.

According to [14], a good convergence is obtained with 100 simulations. This is of course dependant of the model and the input data.

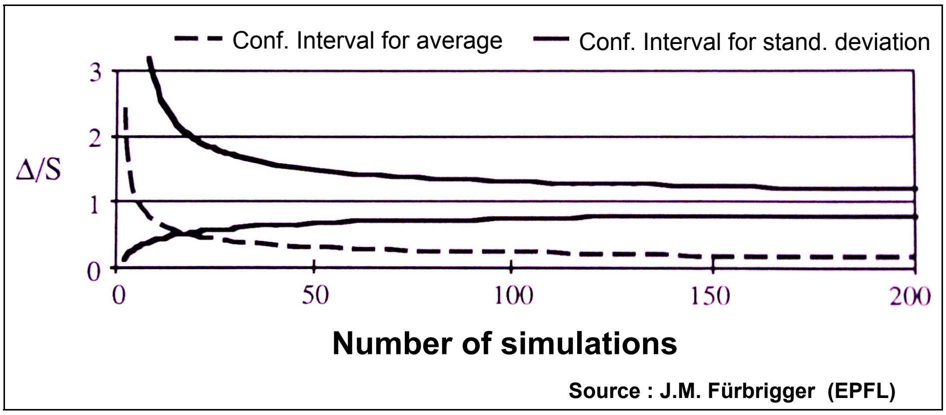


Figure 16: Number of simulations required for the Monte-Carlo process

5.3.5 Random Sequences versus Low Discrepancy Sequences

Researches [15] have shown that the Monte-Carlo process can be speeded up by using *Low Discrepancy Sequences* instead of random numbers. This deterministic alternative is also known as *Quasi-random Monte Carlo* method.

Low Discrepancy Sequences (LDS) are also called quasi-random numbers, which in fact are not random at all. The basic idea of n-dimensional LDS is the following: instead of randomly sampling points in the n-dimensions, the points are distributed to empty areas in a way to prevent overlappings and clusters, which are very common with ordinary random numbers. This is illustrated in Figure 17 for a 2-dimensional sequence. On the left, 63 numbers are randomly chosen (with the "rand()" function of MS Excel). On the right, the 63 first numbers of a 2-dimensional LDS produced by Sobol's algorithm are presented[7]. The comparison between both figures shows that the 2-dimensional space is much better covered by the LDS than by the random sequences, where empty areas (and consequently clusters of points) can clearly be seen.

[7] These values have been taken from the COMISexcel user interface developed by Peter G. Schild ([26]). For a description of the Sobol's algorithm, the reader could refer to [26].

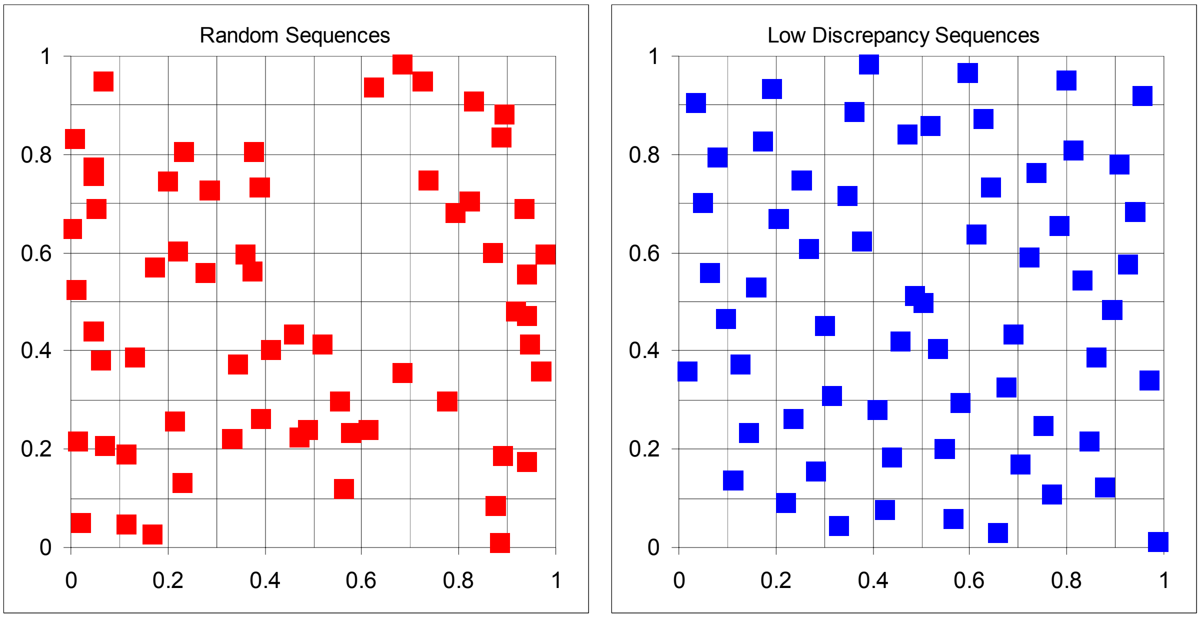


Figure 17: Random Sequences versus Low Discrepancy Sequences

There are several techniques to generate LDS; the Sobol's algorithm is one of them. The special feature of Sobol's sequence is its excellent sub-randomness (see Figure 18), i.e. the way that the sample points are always uniformly spaced, no matter the number of dimensions of the sequence or the number of samples that have been taken. This is especially useful for Monte-Carlo processes for which there is no predefined number of samples.

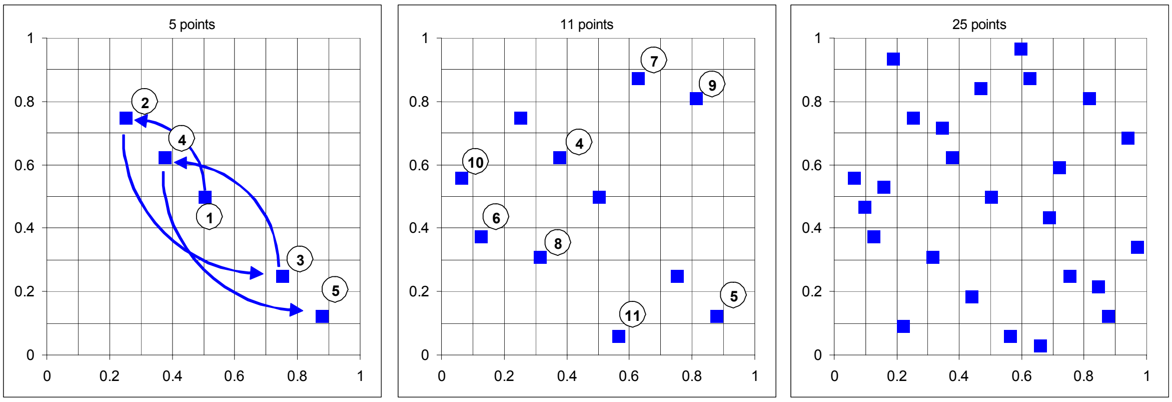


Figure 18: How Sobol's algorithm works (in a two-dimensional space)…

It must be stressed that, in order to fill the gap of the n-dimensional space, the different dimensions have to be correlated. That is why, if the number of dimension is high, two of the high dimensions will be correlated in a way that induces terrible gaps in the distribution of points. These gaps will disappear if a very large number of simulations are carried out, but then the advantages of using LDS are lost. Therefore, it is fully possible to use quasi-random sampling for a limited number of dimensions, and use a more simple pseudorandom sampling method for the remaining dimensions. The most important parameters can beneficially be among the first dimensions, as they will be a bit better resolved than the remaining dimensions. This hybrid Monte Carlo process will still always converge faster than one using only pseudorandom sampling for all dimensions.

Another advantage to use LDS is that these sequences are entirely repeatable, giving the same reliable sequence every time, irrespective of software platform, which could be beneficial for standardisation.

A quirk of Sobol's sampling sequence is that it has a slightly repetitive pattern. It converges faster for smooth continuous functions than for stepped discontinuous functions. This means that the advantage of Sobol over pseudo-random sampling is a bit less for functions with step discontinuities, e.g. occupancy/vacancy or window open/closed.

However, if it is intended to perform a predefined number of samples (e.g. 100), then it is actually most efficient to use uniformly spaced samples in each dimension (i.e. a uniform grid of samples).

5.3.6 How to use the results to improve the design of the innovative system and/or of the building?

Sensitivity analyses might be more relevant than the Probabilistic Approach to improve the design of innovative systems. Indeed, sensitivity analyses allow to see the influence of each analysed parameter, whereas the Probabilistic Approach is much more a "black box" where the influence of a specific parameter is hidden. However, the optimisation of a full system might be different than the optimisation of each component. The Probabilistic Approach becomes interesting to check this.

A good Probabilistic Approach tool should also be usable to perform sensitivity analyses as well.

5.3.7 How to make the link between the simulation results and the EPB regulations?

This question is of course of first importance. However, it is quite difficult to answer it because the answer will highly be dependent on the national EPB regulations.

A difference between national legislations is the way ventilation and infiltration have been introduced in the standard procedure. For instance, in Belgium, the assumed yearly average airflow is derived from a combination of the Belgian standard for ventilation requirements (NBN D50-001 ([16])) and data about recent dwellings, whereas in Netherlands, it is derived from a combination of assumptions derived from field experiments in combination with computer simulations.

How is the ventilation introduced in the Belgian standard procedures?

For instance, in Belgium[8], ex-/infiltration and airflows for hygienic ventilation are given by:

$$\dot{V}_{in/exfilt} = 0.04 \times \dot{v}_{50} \times A_T$$

$$\dot{V}_{dedic} = (0.2 + 0.5\exp(-V/500)).m.V$$

where:

- A_T is the surface of the building envelope, expressed in [m²].
- $\dot{v}_{50}$ is the leakage airflow at 50 Pa for a envelope surface of 1 m², in [(m³/h)/m²], determined with a pressurization test. If no test result is available, the default value is 12 (m³/h)/m², which corresponds to a quite leaky building (but not exceptional in Belgium).
- V_{dedic} is the intended ventilation airflow, in [m³/h].
- m is a correction factor that depends on the ventilation strategy and that takes into account the presence of self-regulating inlet for natural supply, the lack of air tightness of extract ducts, imperfections of mechanical supply and/or extract. It varies between 1.0 and 1.5 (default value).
- V is the volume of the building.

These equations are not the result of simulations but are derived from evaluations carried out on a series of relative new dwellings in the frame of the SENVIVV project ([17]).

In the case of the reference building D4c proposed by WP5 ([18]), V = 373 m³ and A_T = 320 m². Therefore, $\dot{V}_{in/exfilt}$ = 154 m³/h (this corresponds to a n_{50} = 10 h^{-1}) and $\dot{V}_{dedic}$ = 245 m³/h.

Consequently, in order to compare an innovative system simulated in the reference building with a traditional ventilation system (e.g. natural ventilation system), the first step should be to simulate the traditional ventilation system.

The easiest option would be that the traditional ventilation system exactly gives an average $\dot{V}_{in/exfilt}$ equal to 154 m³/h and an average $\dot{V}_{dedic}$ equal to 245 m³/h. In this case, the assessment of the innovative system in the EPB regulation is quite straightforward: the values of $\dot{V}_{in/exfilt}$ and $\dot{V}_{dedic}$ should be replaced by the average values given by the Probabilistic Approach.

However, the values $\dot{V}_{in/exfilt}$ and $\dot{V}_{dedic}$ given by simulations of the traditional system depend of course on the boundary conditions assumed (or imposed) for the simulations. In order to find the same values that those given by the standard procedure, a long tuning process of the assumption would be necessary. This tuning process will even more complicated, due to the fact that, in the Belgian standard procedure, the values $\dot{V}_{in/exfilt}$ and $\dot{V}_{dedic}$ are independent of the type of traditional ventilation system (natural ventilation, fan assisted supply air ventilation, fan assisted exhaust ventilation, fan assisted balanced

[8] Note that the procedure is actually developed for the Flemish Region of Belgium. For the Belgian building sector, it is of first importance that the other Regions take over the same procedures.

ventilation).

Another option could be to replace the values of $\dot{V}_{in/exfilt}$ with

$$\dot{V}_{dedic} = \dot{V}_{dedic/innovative/PA} \times \frac{\dot{V}_{dedic/ref/EPBR}}{\dot{V}_{dedic/ref/PA}}$$

where $\dot{V}_{dedic/innovative/PA}$ is the average value given by the Probabilistic Approach simulations for the innovative system, $\dot{V}_{dedic/ref/PA}$ is the average value given by the Probabilistic Approach simulations for the reference system and $\dot{V}_{dedic/ref/EPBR}$ the value given by the standard procedure for the reference system.

In this case, a reference ventilation system should be chosen (more or less arbitrarily) among the four traditional ventilation systems. This can lead to a situation where even another traditional system would have a better performance if it is evaluated by a PoE analysis than by the standard procedure, which is of course not the intention.

Example 7: Ventilation in the Belgian standard procedure

How is the ventilation introduced in the Dutch standard procedures?

In The Netherlands, the performances of the ventilation systems in dwellings have been investigated by TNO Building and Construction Research.

The yearly ventilation and energy performances of a standard single dwelling inhabited by a standard four persons family were analysed by simulations, carried out with the software VENCON [19]. The effects of the following aspects were analysed:

- Type of ventilation system:
  - Natural supply and exhaust,
  - Natural supply and mechanical exhaust,
  - Mechanical supply and exhaust with heat recovery.
- Air tightness level of the dwelling.
- Use of the ventilation provisions such as windows, doors, grilles and switch position of the mechanical exhaust and or supply.
- Distribution of persons over time in the different rooms.

The results of this study in terms of indoor air quality expressed as L_{vi} and heating season energy use were the basis for the equation ($q_v = 0.47\ A_g + 0.13\ q_{v10}$) in the Dutch standard NEN 5128 for the energy performance of dwellings. Consequently, only two parameters have to be taken into consideration for the energy performance of ventilation systems: the floor area of occupation of the dwellings A_g [m^2], and the air tightness of the dwelling at 10 Pa q_{v10} [dm^3/s].

The airflow q_v [dm^3/s] takes into account the

- the purpose provided ventilation through the system including a certain behaviour
- the infiltration,

- the airing (window opening),
- the cross flow.

The important evaluation parameter for ventilation or indoor air quality is the Low Ventilation Index (L_{vi}). L_{vi} is the integration of the time each person in the dwelling exceeds for the CO_2 concentration limit and the exceeding concentration. As a critical limit, the CO_2 concentration of 1200 ppm was taken based on the Dutch Building Decree.

Consequently, if the PoE is carried out with the same set of assumptions and the same model as the ones used to determine the standard equation of NEN 5128, new coefficients can be directly derived from the simulations of the innovative system, as it was the case in Example 4.

Example 8: Ventilation in the Dutch standard procedure

From these examples, it can be conclude that the application of the PoE seems to be easier in EPB regulations where ventilation aspects have been determined by simulations (as in The Netherlands) than those where they have been determined from measurements (as in Belgium) or other methods. Anyway, in both case, the easiest way is to replace some coefficients by the average values given by the Monte-Carlo process.

However, the Probabilistic Approach gives not only an average value but a full distribution and the PoE procedure should use this information for the assessment of innovative systems. Some options could be:

- Not to use the average values, but values that correspond to another probability; but in this case, again only one value is used.
- To use one value, but to have also a criterion to prevent too high energy consumption (e.g. the probability that the energy consumption is higher than X should be lower than Y%) and too low IAQ.
- …

Part 2: Example of the application of the Probabilistic Approach to a ventilation system

6 PARAMETERS TO BE INCLUDED AS STOCHASTIC PARAMETERS IN THE PROBABILISTIC APPROACH

In order to determine the parameters that should be included in a Probabilistic Approach, focus groups have been organised with RESHYVENT experts (who had a good knowledge in the fields of hybrid ventilation systems, EPBD and building simulation). The list of parameters given below should not be considered as a "final list" of relevant parameters to include as stochastic parameters in the Probabilistic Approach, but only as the list of parameters for which there was a good consensus among the experts. This list should be adapted according to the actual application of the PoE in the different Member States, the evolution of the building simulation programs and of the computer capabilities, as well as the work of the relevant CEN technical committees.

As proposed by the RESHYVENT WP5 "Design parameters support unit" ([20]), the input will be divided in three groups:

1. inputs related to **design constraints** (as climatic conditions and occupancy pattern),
2. inputs related to the **building** (as type of building, building air tightness, c_p coefficients…),
3. inputs related to the **ventilation system** (as component characteristics…).

The paragraphs below will focus on the case of a PoE analysis applied for an innovative system, and not for a specific building (in this case, the list would be much shorter).

6.1 INPUT RELATED TO DESIGN CONSTRAINTS

6.1.1 Outdoor climate

The outdoor climate includes several parameters as temperature, humidity, wind characteristics, solar radiation, outdoor level of pollutants including CO_2, barometric pressure, infrared radiation… This list can of course vary from one EPB regulation to the other, as well as from one building simulation program to the other. For some countries, it might be preferable to define various climatic regions, as the outdoor climate may considerably vary from one side of the country to the other one (for instance, the RT2000 divides France into 3 regions).

Should the outdoor climate be introduced as a stochastic parameter of the Monte-Carlo process?

- Technically, it seems difficult to introduce the climatic regions as stochastic parameter parameters of Monte-Carlo process. If a country is divided in several climatic regions, it seems preferable to do the PoE analysis for each of them.
- On one hand, some experts estimate that the outdoor climate should not be part of the Monte-Carlo process because the weather contains itself a stochastic aspect as it varies considerably during a year. On the other hand, if only one weather file is used, the ventilation strategy could be tuned according to that specific weather data, which is precisely what the Probabilistic Approach tries to prevent.
- In any case, if the outdoor climate is introduced as a stochastic parameter, it is important to take into account the cross-correlations between the various parameters.

Note that usually, the wind characteristics given in weather data file are coming from meteorological stations located in open terrain as airport. These data have to be transformed to local wind characteristics. Several models exist to transform wind speed according to the terrain roughness (at a macro-scale), whereas the wind direction is usually left unchanged.

Should the terrain roughness be introduced as a stochastic parameter of the Monte-Carlo process?

- During the discussions, about half of the RESHYVENT experts considered that this aspect should be introduced stochastically.
- Technically, it seems that the terrain roughness can be introduced as a stochastic parameter without any problem.

6.1.2 Occupancy pattern and building use

Obviously, occupant behaviours have a very large impact on the building performances. Two main questions related to occupancy must be answered:

- **When will the occupants be in the building? And where? (Occupancy pattern)**
  Some people are inside their dwellings during a large part of the time (e.g. elderly people), whereas others will often leave it (e.g. working people, children at school age…). The location of each occupant inside the building must also be specified.
- **How will the occupants use the building and the ventilation system?**
  Some people will keep the windows as closed as possible, whereas others will open them every time it is possible. The use of the ventilation system, the heating system… will also differ considerably from one user to the other.

Even in a deterministic approach, it is clear that appropriate occupancy pattern and building use assumptions have to be proposed. On one hand, the occupancy must not be too low: empty buildings will not present difficulties to satisfy IAQ criteria! On the other hand, occupancy must not be too high but must be enough realistic, so that the predicted performances of the building/system are more or less in line with the actual performance of the building/system.

Should the occupancy pattern and the building use be introduced as stochastic parameters of the Monte-Carlo process?

- During the discussions, a majority of the RESHYVENT experts considered that the occupancy pattern should be introduced stochastically.
- Experts also considered that the water vapour production due to cooking and showers and the windows and doors opening should be considered in the Monte-Carlo process.
- Some experts also considered that the set points for the heating system should also be considered, as they influence the performances of some ventilation system, as humidity-controlled ventilation (widely used in France).

- Obviously, if the occupancy pattern is the same for every day or even for every weekday and every week-end day, the system that will deliver the best IAQ at the lower energy penalty is a time-controlled system. This system could even take into account window opening, as they are known in advance with precision. Based on such deterministic assumptions, a CO_2 controlled ventilation system will be more expensive, but will not offer any improvements. From this point of view, it seems obvious that the occupancy pattern and the building use are input data that should be introduced in the Monte-Carlo process as stochastic parameters.
- Practically, two options can be considered, as illustrated in Figure 19.
  1. The first option consists of creating a different pattern for each simulation. This is the "option 1" of Figure 19. The occupancy level is represented by blocks (black = week, grey = week-end). As can be seen, the occupancy varies from day to day but also from simulation to simulation. Moreover, the first day of the period is a different day of the week at each simulation, in order to break any relationship between the occupancy and the weather conditions.

2. It could be argued that the year includes 365 days, or ± 261 week days and 104 week-end days. In order to reduce the (time consuming) process of creating occupancy patterns, it could be possible to use this large number of days to make a pattern which would vary from day to day, but that could be used for each simulation of the Monte-Carlo process. This is the "option 2" of Figure 19. Only one full year pattern is created (simulation 1). For the other simulation runs, the same pattern is used, but the first day of the year is stochastically chosen among the 365 days (e.g. Saturday 06/01 of simulation 2, Tuesday for simulation 3 and so on…)

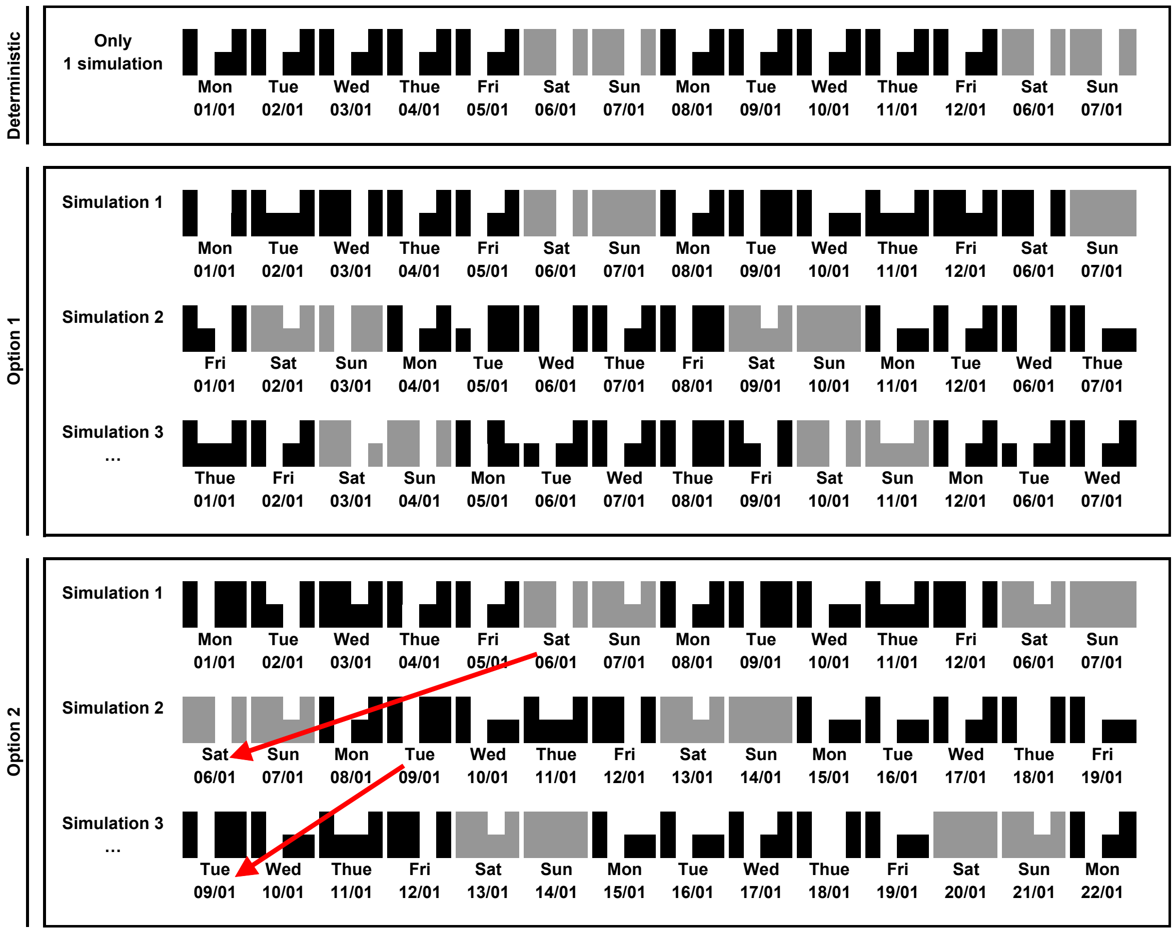


Figure 19: Possible scenarios for occupancy patterns (the number of occupants is represented by the blocks)

- In order to simplify the process of creating stochastic occupancy patterns for COMIS, a dedicated tool has been developed by BBRI in MS Excel. The first version of this tool is presented in Annex 2.
- Another stochastic model for the occupancy, based on the probability of presence of the occupant, has been proposed in the RESHYVENT WP5 technical report "Description of reference buildings and ventilation systems" ([17]).
- This document also proposes a stochastic window opening model and a stochastic model for the manual control of the ventilation system.

6.1.3 Other parameters related to occupancy or occupants

Should other parameters related to occupancy or occupants be introduced as stochastic parameters of the Monte-Carlo process?

- Some RESHYVENT experts considered that other parameters should be considered, as CO_2 production per person, water vapour production per person and internal heat production per person.
- It must be noticed that some RESHYVENT experts considered that water vapour is currently not well modelled in most simulation tools and that, in case it is needed for control purposes, e.g. humidity controlled inlets, other and better models are necessary.
- In case water vapour is considered in the Monte-Carlo process, the hygroscopic inertia of the walls and furniture must also be considered, as it plays an important role in any system including zone humidity control.

6.2 INPUTS RELATED TO THE BUILDING

6.2.1 Building type

Obviously, the same innovative ventilation system will deliver very different performances in single-family houses than in apartment buildings.

Should the building type be introduced as a stochastic parameter of the Monte-Carlo process?

- Definitively not. The building type will define the whole model to be simulated, and can not be changed from one simulation to the other.
- The PoE analysis should only be valid for buildings which present similar characteristics than the simulated building. In case a system is to be sold in different building type (e.g. single-family houses vs. apartments), various PoE analysis should be carried out.
- Based on previous works, RESHYVENT WP5 "Design parameters support unit" has proposed reference buildings for simulation ([17]).

6.2.2 Building characteristics

The building characteristics (insulation, thermal mass, window areas…) influence the energy consumption of a building. They may vary considerably from one building to the other.

Should the building characteristics be introduced as stochastic parameters of the Monte-Carlo process?

- Probably not (not for methodological reasons but for pragmatic ones).

6.2.3 Building orientation

Building orientation influences the building performances, due to solar course and the dominant wind direction.

Should the building orientation be introduced as stochastic parameters of the Monte-Carlo process?

- As the impact of these aspects on thermal comfort and IAQ is very important, the building orientation could be part of the probabilistic approach. However, during the discussions, only a minority of the RESHYVENT experts considered that the building orientation should be introduced stochastically.
- It is important that the building orientation is chosen with respect to the building design. Not every design can be turned around 360°: for instance, in EU, a house with a high glazing surface on one side will orientate that façade to the South, not to the North. This problem does not occur with the reference building developed by Annex 27 and considered in RESHYVENT (as the glazing surface is almost the same on both sides) but should be kept in mind if other types of building are selected.
- It must be mentioned that the French procedure already takes this parameter into account. In the SIREN simulations, the building orientation is changed each week in order to inverse the windward and leeward façades, so that the influence of the crossing flows due to wind on the IAQ is averaged.

6.2.4 C_p coefficients

Ventilation systems, especially natural and hybrid ventilation systems, are dependent of the wind pressure on the building envelope, which depend on the wind characteristics (see § 6.1.1) and the c_p coefficients. Even if a few tools exist, these c_p coefficients are difficult to predict for a specific building, as they are dependent of the surroundings and the building façades themselves. (See [21]).

Should the c_p coefficients be introduced as stochastic parameters of the Monte-Carlo process?

- During the discussions, a majority of the RESHYVENT experts considered that the c_p coefficients should be introduced stochastically, due to their high impact on the results.
- If the c_p coefficients are introduced as stochastic parameters, it must be taken into account the cross correlations between them.
- A model that takes into account the cross-correlation has been proposed in the RESHYVENT WP5 technical report "Description of reference buildings and ventilation systems" ([17]).

6.2.5 Building air tightness

Building air tightness is another parameter that has a large impact on the airflows in a dwelling (see [22]).

6.2.5.1 The global building air tightness: n_{50} value.

The building air tightness is usually described by its n_{50} value, which corresponds to the number of air changes due to the leakages at an indoor-outdoor pressure difference of 50 Pa. The main advantage to present the building air tightness with a single n_{50} value is that it is very easy to compare buildings.

Annex 27 proposes three classes of air tightness (see Table 3). The SENVIVV study in Belgium ([17]) has shown that the new Belgian dwellings are usually not very airtight, and that the spread is very large (n_{50} between 1.8 h^{-1} and 25 h^{-1} – average of the 50 dwellings tested: 7.8 h^{-1}). The n_{50} value depends on the building type; the apartments are usually more airtight than the dwellings.

Class	n_{50} [h^{-1}]
Tight	1.0
Average	2.5
Leak	5.0

Table 3: Overall leakages (n_{50}) for D4c house (as proposed by Annex 27)

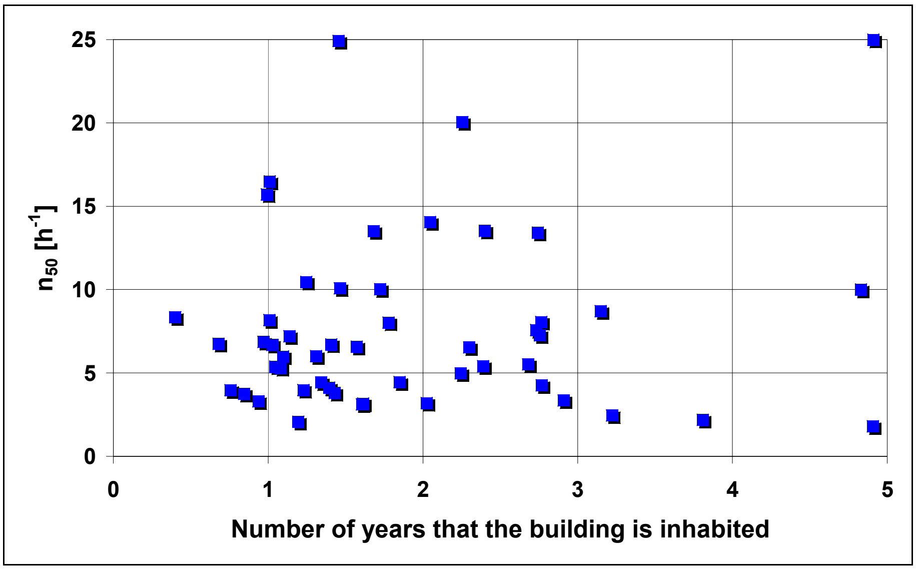


Figure 20: Global building air tightness (n_{50} value) versus numbers of years of occupancy in recently built Belgian dwellings ([17]).

6.2.5.2 The global air tightness: C and n coefficients

It must be noted that the n_{50} value is not sufficient to correctly define the air tightness of a building, as cracks in the building envelope are assumed to follow a power equation:

$$Q = C.\Delta P^{n}$$

where Q is the airflow [l/s], the flow exponent n is between 0.5 and 1.0 [#], ΔP is the pressure difference [Pa] and C is the airflow at a pressure difference of 1 Pa [l/s@1Pa].

Annex 27 assumed the flow exponent n to be equal to 0.66. Consequently, the three classes become:

Class	n_{50} [h^{-1}]	C [kg/s@1Pa]	n [#]
Tight	1.0	0.00531	0.66
Average	2.5	0.0133	0.66
Leak	5.0	0.266	0.66

Table 4: Overall leakages (C,n) for D4c house (as proposed by Annex 27)

The assumption on the flow exponent are confirmed by e.g. Technical Note AIVC 44 ([23] and [24]), which presents a summary of 1758 air tightness measurements carried out in 5 countries. From these measurements, it appeared that that the exponent n was normally distributed about a mean value of approximately 0.65, but that there was no clear link between the n_{50} value and the exponent n. This value has been confirmed since by several studies, including the SENVIVV survey (0.62).

AIVC TN 44 also gives flow exponents for some leakage types. The majority of flow exponents for leakages at joints or material interfaces were fount to be within ±0.1 of their mean value 0.6, whereas the flow exponent for porous surfaces (walls) varied between 0.5 and 1.0. Measurements carried out in the IDEE house in Belgium have shown a relationship between C and n (see § 7.5.1).

6.2.5.3 Location of cracks

Moreover, the locations of the cracks are also influencing the airflow in the dwelling.

Annex 27 proposes to distribute the building leakage in relation to the room floor areas. However, this assumption could be too simple, as it is possible to find very airtight rooms (especially bedrooms) in very leaky dwellings (as the SENVIVV survey has shown in Belgium ([17])). Therefore, the IAQ in the bedrooms can not be guaranteed thanks to infiltration, even in a leaky house (see Figure 22).

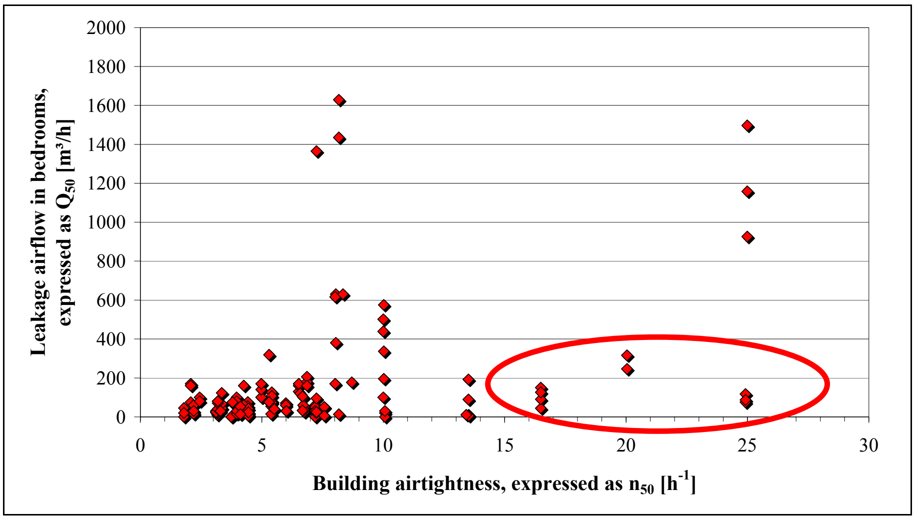


Figure 21: Bedroom air tightness (Q_{50} [m³/h]) versus building air tightness (n_{50} [h^{-1}])

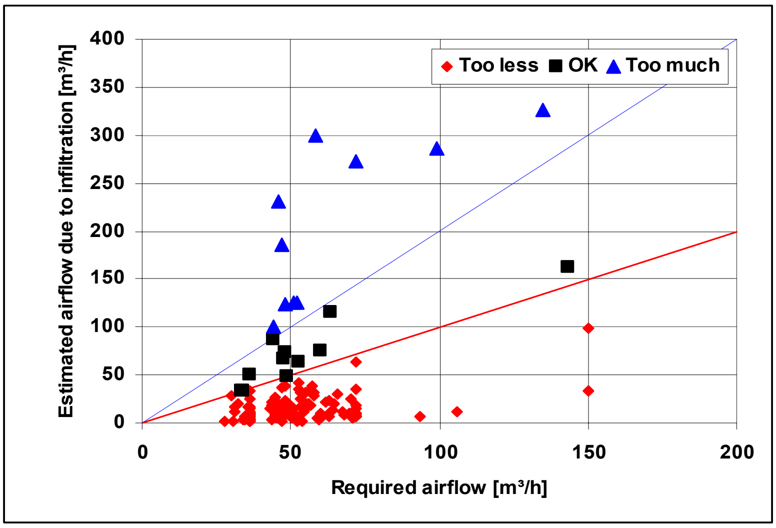


Figure 22: Typical airflow due to infiltration in bedrooms

Should the parameters related to building air tightness be introduced as stochastic parameters of the Monte-Carlo process?

- During the discussions, there was great consensus among RESHYVENT experts: the building air tightness is one of the main parameters to be introduced as a stochastic parameter of the Monte-Carlo process.
- Practically, **a distribution of global air tightness n_{50} must be defined according to the national situation**. This distribution should ideally be different for each type of dwelling (e.g.: apartment, 2 façade single-family house, 3 façades single-family house, isolated single-family house).
- If not only the global n_{50} value but also the C and n parameters are introduced stochastically, the correlation between C and n must be analysed more in detail. Due to a lack of data, this seems difficult to implement for the moment. The flow exponent

could be set to 0.66, as proposed by Annex 27.

- The locations of the cracks and the repartition of the cracks on the wall of a specific room could be part of the probabilistic approach without technical problem, but first simulations have shown that the impact of these parameters (for the case simulated) is limited.
- Assumptions should be done at national level, as the building techniques and construction habits may vary a lot from one country to the other.

6.3 INPUT RELATED TO THE VENTILATION SYSTEM

6.3.1 Component characteristics

The modelling of air distribution systems is very important, and in particular for hybrid ventilation systems.

Elements of concern are:

- ductwork leakage,
- ductwork pressure losses,
- combined driving pressure wind-temperature-fan,
- quality of the system,
- …

Should the component characteristics be introduced as stochastic parameters of the Monte-Carlo process?

- Some RESHYVENT experts considered that the quality of the system, expressed for instance as the ratio actual airflow/design airflow, might be introduced in the Monte-Carlo process.

7 EXAMPLE OF THE APPLICATION OF THE PROBABILISTIC APPROACH ON A VENTILATION MODEL IN COMIS

In this chapter, the application of the Monte-Carlo process on a building simulated in COMIS will be presented to illustrate practical considerations for the implementation of the Probabilistic Approach.

In order to set up the COMIS model, a user interface in Microsoft Excel has been developed[9].

7.1 BUILDINGS USED IN THE SIMULATIONS

Although RESHYVENT WP5 has proposed reference building for simulations ([17]), this analysis has been carried out on an existing building: the IDEE house (located at BBRI test facilities).

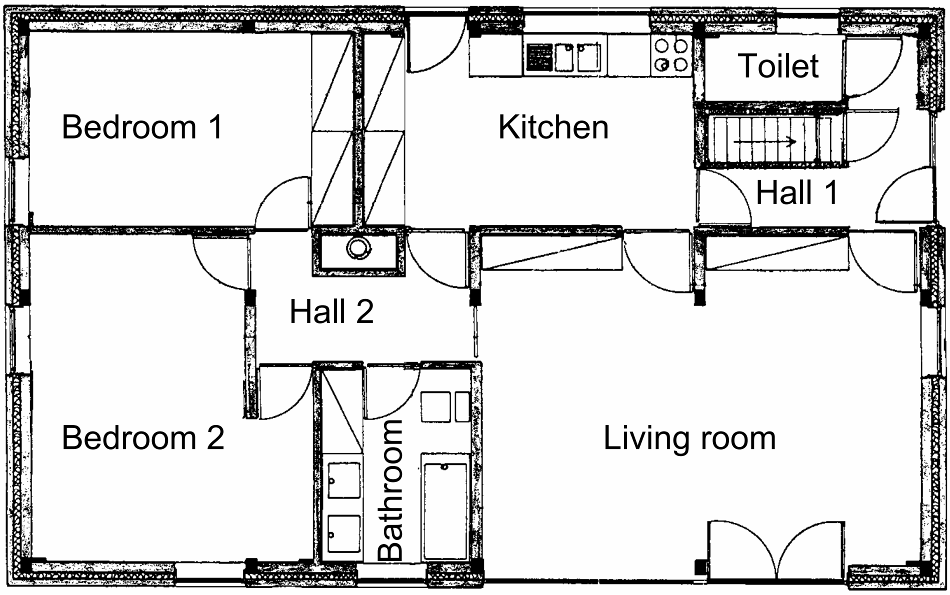


Figure 23: Floor plan of the IDEE house

The IDEE house is a small bungalow (one habitable floor) with two rooms, a living room, a bathroom, a toilet and a kitchen (see Figure 23). The gross surface area of the room (excluding attic) is 13.1 x 8.2 = 107.4 m². The surface of each room is given in Table 5. The house is supposed to be inhabited by 4 persons (2 adults in bedroom 2 and 2 children in bedroom 1).

[9] This Excel user interface is on a large scale based on the COMISexcel user interface developed by Peter G. Schild ([26]).

7.2 VENTILATION OF THE IDEE HOUSE

In Belgium, ventilation of dwellings is described by the Belgian standard NBN D 50-001 ([16]). Basically, air must be supplied into the "dry" rooms and exhausted out of the "wet" rooms; air transfer devices must be installed between dry and wet rooms. Both the supply and exhaust can be natural or mechanical, so four types of systems are allowed by the standard:

- System A: natural supply and natural exhaust (natural ventilation)
- System B: mechanical supply and natural exhaust (fan assisted supply air ventilation)
- System C: natural supply and mechanical exhaust (fan assisted exhaust ventilation)
- System D: mechanical supply and mechanical exhaust (fan assisted balanced ventilation)

In the present study, a hybrid system (called "system H") has been compared to a system C (fan assisted exhaust ventilation).

As a general rule, the airflows to provide are 3.6 m³/h.m²; however, minimum and recommended maximum values are given for each type of room. There is also an absolute maximum airflow in case of natural inlets: two times the nominal airflow.

In the case of the IDEE house, the required airflow rates are given in Table 5.

Room	Surface	Flow pattern	Minimum	Maximum (recommended)	Nominal airflow
Living room	28.8 m²	Inlet	75 m³/h	150 m³/h	103.7 m³/h
Bedroom 1	12.7 m²	Inlet	25 m³/h	36 m³/h.person	45.5 m³/h
Bedroom 2	17.1 m²	Inlet	25 m³/h	36 m³/h.person	61.5 m³/h
Hall 1	6.3 m²	Transfer	-	-	(22.5 m³/h)
Hall 2	4.7 m²	Transfer	-	-	(16.9 m³/h)
Kitchen	12.5 m²	Exhaust	50 m³/h	75 m³/h	50 m³/h
Bathroom	6.1 m²	Exhaust	50 m³/h	75 m³/h	50 m³/h
WC	-	Exhaust	25 m³/h	25 m³/h	25 m³/h

Table 5: Airflow required in the IDEE house

Remarks:

- The standard does not require the nominal supply and exhaust rates to be balanced. In the case of the IDEE house, the nominal supply rate (210.7 m³/h) is higher than the nominal exhaust rate (125 m³/h).
- The airflow in hall 1 and hall 2 can be provided by air transferred from the dry rooms to the wet rooms.
- The standard requires the dwelling to be equipped with a ventilation system but does not aim to deal with the use of the system by the occupant. Consequently, the occupant can

use it according to his wishes; he can for instance close all natural inlet and outlet devices if he wants!

7.3 MODELLING A SYSTEM C (FAN ASSISTED EXHAUST VENTILATION) IN COMIS

7.3.1 Supply air terminal devices

According to NBN D 50-001, the supply air terminal devices for natural supply must be designed to give the nominal airflow rate for a pressure difference of 2 Pa.

Usually, the supply air terminal device will be a ventilator located at top of the windows. The airflow rate of these air inlets, if not self-regulating, will follow a law like $Q = C.\Delta P^n$, where n is usually equal to 0.5.

Figure 24: Air inlet RENSON THR-90

The nominal airflow of such a ventilator is generally given as a function of its length. An example is given in Figure 24. According to RENSON documentation, the nominal airflow of this ventilator is 72 m³/h.m @ 2 Pa and 162 m³/h.m @ 10 Pa, or $Q = 50.8.\Delta P^{0.5}$ m³/h.m.

In a real house, the length of the ventilator will be chosen according to the length of the actual window. In the simulations of the IDEE house, the ventilator will be chosen so that it exactly complies with the standard.

Room	Nominal airflow	Length
Living room	103.7 m³/h	1.44 m
Bedroom 1	45.5 m³/h	0.63 m
Bedroom 2	61.5 m³/h	0.85 m

Table 6: Required length of THR-90 ventilators

In COMIS, the natural supply air terminal devices are simulated as cracks. The coefficients are given in Figure 25. The air mass flow coefficient Cs is given in kg/s @1 Pa; 50.8 m^3/h corresponds to ± 0.017 kg/s. The actual length (as in Table 6) is introduced in the &-NET-LINK section.

&-CR Cracks

1	*CR<name>	Description				
2	Cs	Exp n	Length	**Wall properties**		
				Thickness	U-value	
	(kg/s@1Pa)	(-)	[m]	[m]	[W/m²K]	
3	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	
	(-)	(-)	(-)	(-)	(-)	
	*CR_inlet	Based on THR90 from RENSON (72 m³/h/m at 2 Pa)				
	0.017	0.5	1	d	d	
	0					

&-NET-LINKs

	Link ID	Airflow component ID	**Zone ID** From	To	**Height** From	To	Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction	
	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]	
	L_inLIV	CR_inlet	-EX_S	Living	2.2	2.2	d	1.44			
	L_inR1	CR_inlet	-EX_W	Room1	2.2	2.2	d	0.63			
	L_inR2	CR_inlet	-EX_W	Room2	2.2	2.2	d	0.85			

Figure 25: Natural supply air terminal devices simulated in COMIS

7.3.2 Air transfer devices

According to NBN D 50-001, the air transfer devices between rooms must be dimensioned for a pressure difference of 2 Pa. The minimal nominal airflow rate must 25 m^3/h for each room, excepted for kitchen where 50 m^3/h are required; however, higher airflow rate are recommended for living rooms. It is assumed that openings with a free area of respectively 70 cm^2 and 140 cm^2 comply with the requirement of 25 m^3/h and 50 m^3/h.

The air transfer device can be a louvre inside the door or the wall, or a split under the door.

Remark:

- We have already seen that the standard does not require the nominal supply and exhaust rates to be balanced at building level. This also the case at room level. For instance, for the living room of the IDEE house, the nominal supply rate (103.7 m^3/h) is much higher than the nominal transferred (outgoing) airflow rate (25 m^3/h).

Door	Free area
Living room → Hall 1	70 cm²
Living room → Kitchen	70 cm²
Bedroom 1 → Hall 2	70 cm²
Bedroom 2 → Hall 2	70 cm²
Hall 1 → WC	70 cm²
Hall 2 → Kitchen	70 cm²
Hall 2 → Bathroom	70 cm²

Table 7: Required free area of air transfer devices

In COMIS, natural air transfer devices will be modelled as cracks. The air mass flow coefficient Cs can be calculated by the equation:

$Q = Cd.A.(2.\rho.\Delta P)^{0.5} = 0.61 * 0.007 * (2 * 1.2)^{0.5} * \Delta P^{0.5} = 0.006615\ \Delta P^{0.5}$ kg/s

&-CR Cracks

| 1	*CR<name>	Description				
| 2	Cs	Exp n	Length	**Wall properties**		
|				Thickness	U-value	
|	(kg/s@1Pa)	(-)	[m]	[m]	[W/m²K]	
| 3	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	
|	(-)	(-)	(-)	(-)	(-)	
	*CR_transf					
	0.006615	0.5	1	d	d	
	0					

&-NET-LINks

	Link ID	Airflow component ID	Zone ID		Height		Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction	
|			From	To	From	To					
|	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]	
	L_Door1	CR_transf	Hall1	WC	0.3	0.3	d	1			
	L_Door2	CR_transf	Living	Hall1	0.3	0.3	d	1			
	L_Door4	CR_transf	Living	Kitchen	0.3	0.3	d	1			
	L_Door6	CR_transf	Hall2	Kitchen	0.3	0.3	d	1			
	L_Door7	CR_transf	Hall2	Bath	0.3	0.3	d	1			
	L_Door8	CR_transf	Room2	Hall2	0.3	0.3	d	1			
	L_Door9	CR_transf	Room1	Hall2	0.3	0.3	d	1			
	L_Door1	CR_transf	Hall1	WC	0.3	0.3	d	1			
	L_Door2	CR_transf	Living	Hall1	0.3	0.3	d	1			

Figure 26: Air transfer devices simulated in COMIS

7.3.3 Fan assisted exhaust ventilation

The standard NBN D 50-001 does not give many information about terminal devices for mechanical ventilation. It only specifies that they should be designed and installed in a way that they can be tuned in advance by qualified staff in order to realise the design airflows.

In the case of the SENVIVV house, the extract air terminal devices have been simulated as cracks. The ducts have been simulated according to ducts from AERECO. The fan is supposed to be a "perfect fan" that extracts the design airflow independently of the pressure difference. This "perfect fan" is supposed to run 24 hours a day. Note that this reference system is not very realistic; this is not of first importance here, as the goal of the present study was to show how to carry out the Probabilistic Approach in COMIS, but it should clearly be discussed at national level, when fixing up the boundary conditions for the Principle of Equivalence analysis.

&-CR Cracks

| 1	*CR<name>	Description				
| 2	Cs	Exp n	Length	**Wall properties**		
|				Thickness	U-value	
|	(kg/s@1Pa)	(-)	[m]	[m]	[W/m²K]	
| 3	Filter 1	Filter 2	Filter	Filter 4	Filter 5	
|	(-)	(-)	(-)	(-)	(-)	
	*CR_out50					
	=50/(2^0.5)*1.204/360003600	0.5	1	d	d	
	0					

&-NET-LINKs

|	Link ID	Airflow component ID	**Zone ID**		**Height**		Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction	
|			From	To	From	To					
|	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]	
	L_outBATH	CR_out50	Bath	DummyB	2.53	2.53	d	1			
	L_outKIT	CR_out50	Kitchen	DummyK	2.53	2.53	d	1			
	L_outWC	CR_out50	WC	DummyW	2.53	2.53	d	0.5			

Figure 27: Extract air terminal devices simulated in COMIS

&-DS Straight ducts

1	*DS<name>	Description						
2	**Duct's straight part**					**One fitting**		
	Diameter 1	Diameter 2	Roughness	Length	Zeta	Type	Param 1	Param 2
	(m)	(m)	(mm)	(m)	(-)	[-]	[?]	[?]
3	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5			
	(-)	[-]	[-]	[-]	[-]			
	*DS_V	Vertical duct AERECO						
	0.192	0	0.005	4.25	0	0		
	0							
	*DS_1	Horizontal duct AERECO – WC → Kitchen						
	0.16	0	0.005	3.15	1.11	0		
	0							
	*DS_2	Horizontal duct AERECO – Kitchen → T						
	0.16	0	0.005	4.15	1.22	0		
	0							
	*DS_3	Horizontal duct AERECO – Bathroom → T						
	0.16	0	0.005	3	0.11	0		
	0							
	*DS_4	Horizontal duct AERECO – WC → Kitchen						
	0.16	0	0.005	1.25	0.35	0		
	0							

&-NET-LINKs

	Link ID	Airflow component ID	**Zone ID**		**Height**		Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction
			From	To	From	To				
	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]
	L_duct1	DS_1	DummyW	DummyK	2.53	2.53	d	1		
	L_duct2	DS_2	DummyK	DummyT	2.53	2.53	d	1		
	L_duct3	DS_3	DummyB	DummyT	2.53	2.53	d	1		
	L_duct4	DS_4	DummyT	DummyT	2.53	2.53	d	1		
	L_ductV	DS_V	DummyV1	DummyV2	2.53	6.78	d	1		

Figure 28: Ducts simulated in COMIS[10]

[10] The Zeta coefficients are indicative and have not been verified by AERECO.

&-FA Fans

| 1	*FA<name>	Description					
| 2	Flag	Exp. Polynom	Rho_in	Nfl	Cs	Exp n	
|	(-)	(-)	(kg/m3)	[rpm]	[kg/s@1Pa]	[-]	
| 3	Pmin	Pmax	Slope	Intercept			
|	(Pa)	(Pa)	(m3/s/Pa)	(m3/s)			
| 4	C0	C1	C2	C3	C4	C5	
|	(m3/s)	[m3/s/Pa]	[m3/s/Pa^2]	[m3/s/Pa^3]	[m3/s/Pa^4]	[m3/s/Pa^5]	
| 5-8	fan curve : Pressure rise vs. Flow rate						
|	[Pa]	[m3/s]	[Pa]	[m3/s]	[Pa]	[m3/s]	
| 9	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5		
|	(-)	[-]	[-]	[-]	[-]		
*FA125							
3	d	1.2	1	0	0.65		
d	d	d	d				
d							
0	=125/3600	2	0.034722222	100	0.034722222		
0	0	0	0	0			

&-NET-LINKs

|	Link ID	Airflow component ID	Zone ID		Height		Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction	
|			From	To	From	To					
|	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]	
	L_fan125	FA125	DummyV2	-EX_RF	6.78	6.78	d	1			

Figure 29: "Perfect fan" simulated in COMIS

7.4 SYSTEM H (HYBRID VENTILATION)

The hybrid system[11] simulated in this study is an intelligent system C. It includes presence detection in the different rooms. The control algorithm reduces the airflow in the rooms where nobody is present to a minimum value; it however maintains the balance between the supply and exhaust airflow at building level. The airflows are not measured, only the position of the air inlets and outlets is controlled.

[11] This system will not be presented in detail here, as it contains some components of IC3. However, in this study, the control algorithm is quite different that the one developed by IC3, and must therefore not be considered has the IC3 system.

7.5 Parameters included stochastically in the Monte-Carlo process

7.5.1 Occupancy pattern

Which occupancy pattern to use?

The occupancy pattern that has been set up for the simulations is based on the pattern proposed by RESHYVENT WP5 "Design parameters support unit".

Period	Member of household	Kitchen	Living room	Master bedroom	Bedroom 1	Bedroom 2
Weekdays	man		6-7;18-23	23-6 sleep 23-6		
	woman	7-8;12-13; 17-18	6-7;18-23	23-6 sleep 23-6		
	child 13 y		7-8;18-21		17-18;21-7 sleep 22-7	
	child 10 y		7-8;18-20			17-18;20-7 sleep 21-7
Saturday, Sunday	man		8-10;13-24	24-8 sleep 24-8		
	woman	9-11;17-18	8-9;11-12; 15-17; 18-24	24-8 sleep 24-8		
	child 13 y		10-12;18-24		15-18;24-10 sleep 24-10	
	child 10 y		8-10;13-14; 17-21			14-17;21-8 sleep 22-8

Table 8: Occupancy pattern proposed by WP5 for a 4 person family (source: [20])

This pattern has been adapted to the national situation and to the building. For instance, the youngest child is supposed to stay at home and is therefore supposed to be 3 years old only; the family takes its breakfast in the kitchen and not in the living room, between 7 and 8 o'clock; there is a probability that the father comes back at lunch; there is a pattern of occupancy for the bathroom also; there is a probability that guests comes at evening;… (for details, see Figure 32).

How to simulate occupants and occupancy patterns in COMIS?

In COMIS, occupants must be defined in the "&-OCCUPANt description" section, and the occupancy pattern (which can be a file) in the "&-SCH-OCCupant schedules" section. In the IDEE house model, 5 occupants were defined: 4 inhabitants and 1 visitor.

&-OCCUPANt description

| 1	*No.	Sex	Age	Height	Mass	Base activity	Cigarettes	Name
|	(-)	(-)	[years]	[m]	[kg]	[W/m^2]	[/h]	[-]
| 2	Occupant pollutant source strength							
|	Pollutant 1	Source/Sink	Pollutant 2	Source/ Sink	Pollutant 3	Source/ Sink		
|	[-]	(kg/s)	[-]	[kg/s]	[-]	[olf]		
	*1	MALE	40	d	d	d	0	Father
	CO2	d						
	*2	FEMALE	35	d	d	d	0	Mother
	CO2	d						
	*3	MALE	14	d	d	d	0	Child
	CO2	d						
	*4	FEMALE	3	d	d	d	0	Child
	CO2	d						
	*5	MIXED	40	d	d	d	0	Guest
	CO2	d						

&-SCH-OCCupant schedules

|	*Schedule ID	Time	Zone ID	Activity level factor	Number of occupants			
|	(-)	(-)	(-)	[-]	[-]			
	F: OCC1 OCC1-001.txt							
	F: OCC2 OCC2-001.txt							
	F: OCC3 OCC3-001.txt							
	F: OCC4 OCC4-001.txt							
	F: OCC5 OCC5-001.txt							

Figure 30: Definition of occupant and occupancy schedules in COMIS

How to make to introduce the occupancy pattern as a stochastic parameter?

Both the number of occupants and the occupancy pattern have been introduced as stochastic parameters.

- The number of occupants varies from 1 (one adult) to 4 (two adults and two children); non-realistic occupancy have been excluded (as for instance a child alone or the father, who works, and the baby child, who stays at home). In average, 2.9 people are present in the dwelling, which corresponds more or less of to the dwelling occupancy in Belgium.

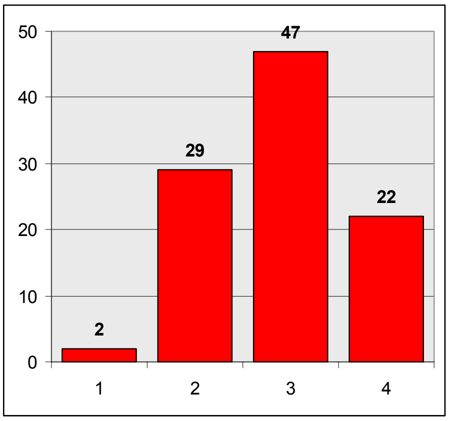


Figure 31: Family size

- To generate random occupancy pattern, the "Occupancy schedules tool for COMIS – version 1" described in Annex 2 has been used. An example of occupancy pattern for occupant 1, obtained with this tool, is given in Figure 33.

Occupancy schedules tool for COMIS.

	Monte-Carlo
From	1
To	100

	Date
From	01/01/03
To	31/12/03

First day: Actual value / Random value

Time step: 00:05

Directory: D:\My Documents\RESHYvent\04 - The Probabilistic Approach\PA2004\Occupancy\

OCCUPANTS	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Occupant 1: father	21	21	21	21	21	106	106
Occupant 2: mother	35	35	35	35	35	119	119
Occupant 3: old child	56	56	68	56	56	132	132
Occupant 4:young child	80	80	80	80	80	147	147
Occupant 5: guests	100	100	100	100	100	162	162

Occupancy schedules tool for COMIS - version 1.3

Occupant 1 - Weekday (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	1	Yes	2		Room2			00:00				00:00	0.7	0.1	0.7	0.71	0.04	0.68
2	1	Yes	3		Bath			06:45	00:15	05:30		06:40	1.2	0.1	1.0	0.32	0.42	0.02
3	1	Yes	4		Kitchen	Living	0.5	06:50	00:05	06:40	07:30	06:55	2	0.1	2.0	0.71	0.61	0.68
4	1	Yes	5		outside			07:45	00:15	06:55	08:00	07:25	2	0.1	2.0	0.09	0.19	0.32
5	0.25	No	6	7	Kitchen			12:30	00:15	12:00	13:00	12:25	2	0.1	2.1	0.33	0.08	0.74
6	1	Yes	7		outside			13:30	00:15	12:55	14:00	13:30				0.45	0.94	0.52
7	1	Yes	8		Living			18:00	00:30	17:30		18:25	2	0.1	2.0	0.78	0.48	0.59
8	1	Yes	9	10	Kitchen			18:15	00:10	18:25		18:25	1.2	0.1	1.2	0.57	0.92	0.46
9	1	Yes	10		Living			18:40	00:10	18:25	23:59	18:45	1.2	0.1	1.2	0.73	0.14	0.47
10	1	Yes	11		Bath			22:50	00:15	22:45	23:59	22:45	1.2	0.1	1.1	0.22	0.45	0.29
11	1	Yes	999		Room2			23:00	00:15	18:45	23:59	23:15	1.2	0.1	1.1	0.87	0.48	0.29

Occupant 2 - Weekday (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	1	Yes	2		Room2			00:00				00:00	0.7	0.1	0.8	0.34	0.88	0.90
2	1	Yes	3		Bath			06:30	00:15	05:30		06:45	1.2	0.1	1.2	0.87	0.06	0.66
3	1	Yes	4		Kitchen	Living	0.75	07:00	00:05	06:45		06:50	2	0.1	1.9	0.02	0.38	0.13
4	1	Yes	5		Living			08:00	00:15	06:50		08:15	1.2	0.1	1.1	0.86	0.47	0.18
5	1	Yes	6		Room1			09:00	00:10	08:45		09:05	2	0.1	2.1	0.60	0.13	0.83
6	1	Yes	7		Room2			09:20	00:10	09:05		09:30	2	0.1	1.8	0.79	0.90	0.01
7	1	Yes	8		Bath			09:45	00:10	09:30		09:30	2	0.1	2.1	0.08	0.63	0.91
8	1	Yes	9		Living			09:45	00:15	06:50	11:00	09:50	1.2	0.1	1.3	0.67	0.27	0.81
9	1	Yes	10		outside			11:00	00:15	09:50		10:50				0.30	0.92	0.51
10	1	Yes	11		Kitchen			12:25	00:15	10:50	12:35	12:20	2	0.1	2.0	0.36	0.09	0.50
11	1	Yes	12		outside			13:30	00:30	13:30		13:30				0.15	0.55	0.50
12	1	Yes	13		Living			14:30	00:30	13:30		14:35	1.2	0.1	1.2	0.60	0.21	0.59
13	1	Yes	14		Kitchen			16:00	00:10	16:40		16:40	2	0.1	1.9	0.99	0.57	0.14
14	1	Yes	15		Living			17:00	00:15	16:40		17:00	1.2	0.1	1.0	0.46	0.65	0.03
15	1	Yes	16		Kitchen	Living	0.75	18:00	00:30	17:00		18:20	2	0.1	2.1	0.73	0.10	0.73
16	1	Yes	17		Living			20:00	00:30	18:20		19:00	1.2	0.1	1.3	0.02	0.32	0.80
17	1	Yes	18		Bath			22:40	00:10	19:00	23:59	22:40	1.2	0.1	1.1	0.46	0.64	0.28
18	1	Yes	999		Room2			22:50	00:15	22:40	23:59	22:45	0.7	0.1	0.7	0.34	0.12	0.60

Occupant 3 - Weekday (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	1	Yes	2		Room1			00:00				00:00	0.7	0.1	0.8	0.78	0.18	0.70
2	1	Yes	3		Bath			07:00	00:15	06:55	07:40	07:05	1.2	0.1	1.2	0.67	0.16	0.63
3	1	Yes	4		Kitchen			07:10	00:05	07:05	07:40	07:15	2	0.1	1.8	0.81	0.22	0.07
4	1	Yes	5		outside							07:25				0.52	0.64	0.53
5	1	Yes	6		Kitchen			16:15	00:10	16:00		16:40	2	0.1	2.0	0.99	0.38	0.39
6	1	Yes	7		Living	Room1	0.75	16:55	00:10	16:40		16:55	2	0.1	2.0	0.53	0.49	0.64
7	1	Yes	8		Living			18:00	00:10	16:55		18:05	2	0.1	1.8	0.60	0.17	0.03
8	1	Yes	9		Bath			22:00	00:15	18:05	23:59	22:25	1.2	0.1	1.2	0.94	0.15	0.36
9	1	Yes	999		Room1			22:15	00:15	22:25	23:59	22:25	0.7	0.1	0.5	0.52	0.37	0.02

Occupant 3 - (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	1	Yes	2		Room1			00:00				00:00	0.7	0.1	0.6	0.36	0.43	0.14
2	1	Yes	3		Bath			07:00	00:15	06:55	07:40	06:55	1.2	0.1	1.3	0.20	0.64	0.89
3	1	Yes	4		Kitchen			07:05	00:05	06:55	07:40	07:00	2	0.1	2.1	0.17	0.18	0.72
4	1	Yes	5		outside							07:25				0.85	0.93	0.20
5	1	Yes	6		Kitchen			13:30	00:10	13:00		13:20	2	0.1	2.0	0.13	0.54	0.37
6	1	Yes	7		Living	Room1	0.75	13:40	00:10	13:20		13:45	2	0.1	1.8	0.62	0.78	0.04
7	1	Yes	8		Living			18:00	00:10	13:45		18:05	2	0.1	2.1	0.74	0.13	0.75
8	1	Yes	9		Bath			22:00	00:15	18:05	23:59	22:20	1.2	0.1	1.1	0.93	0.93	0.27
9	1	Yes	999		Room1			22:15	00:15	22:20	23:59	22:20	0.7	0.1	0.9	0.57	0.59	0.94

Occupant 4 - Weekday (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	1	Yes	2		Room1			00:00				00:00	0.7	0.1	0.7	0.16	0.73	0.54
2	1	Yes	3		Bath			07:30	00:15	06:55		07:20	1.2	0.1	1.1	0.21	0.86	0.07
3	1	Yes	4		Kitchen			07:40	00:05	07:20		07:40	2	0.1	1.9	0.35	0.46	0.25
4	1	Yes	5		Living			08:00	00:10	07:40		08:05	1.2	0.1	1.1	0.74	0.10	0.19
5	1	Yes	6		Living	Room1	0.5	09:00	00:10	08:05		09:00	2	0.1	1.9	0.40	0.55	0.18
6	1	Yes	7		Living							09:05	2	0.1	2.1	0.75	0.53	0.89
7	1	Yes	8		Living	Room1	0.5					09:30	2	0.1	2.0	0.16	0.02	0.38
8	1	Yes	9		outside							10:50				0.64	0.29	0.79
9	1	Yes	10		Kitchen							12:20	2	0.1	1.9	0.85	0.15	0.27
10	1	Yes	11		outside							13:30				0.52	0.88	0.65
11	1	Yes	12		Living	Room1	0.5					14:35	2	0.1	2.0	0.27	0.27	0.61
12	1	Yes	13		Kitchen							16:40	2	0.1	2.1	0.77	0.20	0.90
13	1	Yes	14		Living	Room1	0.75					17:00	2	0.1	1.9	0.78	0.40	0.19
14	1	Yes	15		Kitchen			18:00	00:10	17:30		18:00	2	0.1	2.1	0.52	0.32	0.75
15	1	Yes	16		Living			18:30	00:10	18:00		18:30	2	0.1	1.9	0.42	0.23	0.31
16	1	Yes	17		Bath			19:00	00:15	18:30	19:30	19:10	1.2	0.1	1.0	0.71	0.06	0.02
17	1	Yes	999		Room1			19:15	00:15	19:10	23:59	19:10	0.7	0.1	0.6	0.19	0.89	0.17

Occupant 5 - Weekday (Random values: Event, Hour, Metabol.)

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.	Random Event	Random Hour	Random Metabol.
1	0.1	Yes	2	999	Living			19:30	00:30	19:50	20:50	19:50	6	0.3	6.1	0.05	0.38	0.60
2	1	Yes	999		outside			23:00	00:30	22:30	23:59	1.00				0.96	0.25	0.79

Figure 32: Setting up occupancy pattern for COMIS simulation with the "Occupancy schedules tool for COMIS – version 1" tool

Occupant 1 - Week-end

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.
1	1	Yes	2		Room2			00:00				00:00	0.7	0.1	0.5
2	1	Yes	3		Bath			08:00	00:15	07:45		08:15	1.2	0.1	1.0
3	1	Yes	4		Kitchen	Living	0.75	08:25	00:05	08:15		08:20	2	0.1	1.9
4	1	Yes	5		Living			08:20	00:15	08:20		08:20	1.2	0.1	1.2
5	1	Yes	6		outside			10:30	00:10	08:50		10:20			
6	1	Yes	7		Living			14:30	00:10	10:20		14:35	2	0.1	2.1
7	0.5	No	8	9	Kitchen			18:15	00:10	14:35		18:15	1.2	0.1	1.2
8	1	Yes	9		Living			18:30	00:10	18:15	23:59	18:30	1.2	0.1	1.3
9	1	Yes	10		Bath			22:50	00:15	18:30	23:59	22:55	1.2	0.1	1.4
10	1	Yes	999		Room2			23:00	00:15	22:55	23:59	23:20	1.2	0.1	1.2

Random values

Event	Hour	Metabol.
0.73	0.98	0.00
0.80	0.25	0.06
0.10	0.71	0.19
0.51	0.18	0.46
0.18	0.03	0.41
0.63	0.34	0.81
0.57	0.93	0.33
0.43	0.20	0.82
0.59	0.10	0.98
0.88	0.84	0.68

Occupant 2 - Week-end

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.
1	1	Yes	2		Room2			00:00				00:00	0.7	0.1	0.6
2	1	Yes	3		Bath			07:45	00:15	07:30		07:40	1.2	0.1	1.1
3	1	Yes	4		Kitchen	Living	0.75	07:50	00:05	07:40		07:50	2	0.1	2.1
4	1	Yes	5		Living			08:00	00:15	07:50		07:50	1.2	0.1	1.2
5	1	Yes	6		outside							10:20			
6	1	Yes	7		Living							14:35	2	0.1	2.0
7	1	Yes	8		Kitchen			17:30	00:10	14:35		17:15	1.2	0.1	1.2
8	1	Yes	9		Living			18:00	00:10	17:15	23:59	18:10	1.2	0.1	1.1
9	1	Yes	10		Bath			22:40	00:15	18:10	23:59	22:15	1.2	0.1	1.3
10	1	Yes	999		Room2			22:50	00:15	22:15	23:59	23:00	1.2	0.1	1.1

Random values

Event	Hour	Metabol.
0.30	0.90	0.12
0.38	0.05	0.09
0.52	0.54	0.69
0.07	0.11	0.42
0.40	0.14	0.58
0.20	0.72	0.45
0.04	0.89	0.68
0.79	0.68	0.24
0.04	0.61	0.72
0.70	0.52	0.12

Occupant 3 - Week-end

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.
1	1	Yes	2		Room1			00:00				00:00	0.7	0.1	0.6
2	1	Yes	3		Bath			08:00	00:15	08:20		08:20	1.2	0.1	1.3
3	1	Yes	4		Kitchen	Living	0.75	08:30	00:05	08:20		08:30	2	0.1	2.1
4	1	Yes	5		Kitchen			10:00	00:15	08:30		09:45	1.2	0.1	1.1
5	1	Yes	6		outside							10:20			
6	1	Yes	7		Living							14:35	2	0.1	2.0
7	1	Yes	8		Kitchen							17:15	1.2	0.1	1.5
8	1	Yes	9		Living	Room1	0.5	17:30	00:10	17:15		17:40	1.2	0.1	1.2
9	1	Yes	10		Kitchen			18:15	00:15	17:40		18:35	1.2	0.1	1.2
10	1	Yes	11		Living			18:55	00:10	18:35		19:00	1.2	0.1	1.2
11	1	Yes	12		Bath			22:00	00:15	19:00		22:15	1.2	0.1	1.2
12	1	Yes	999		Room1			22:10	00:15	22:15	23:59	22:20	1.2	0.1	1.1

Random values

Event	Hour	Metabol.
0.91	0.97	0.27
0.62	0.80	0.81
0.58	0.55	0.71
0.14	0.52	0.08
0.29	0.19	0.32
0.12	0.09	0.31
0.68	0.14	1.00
0.88	0.28	0.63
0.90	0.35	0.59
0.77	0.52	0.59
0.84	0.43	0.60
0.70	0.52	0.12

Occupant 4 - Week-end

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.
1	1	Yes	2		Room1			00:00				00:00	0.7	0.1	0.7
2	1	Yes	3		Bath			08:00	00:15	08:20		08:20	1.2	0.1	1.3
3	1	Yes	4		Kitchen	Living	0.75	08:30	00:05	08:20		08:30	2	0.1	2.0
4	1	Yes	5		Kitchen			10:00	00:15	08:30		10:05	1.2	0.1	1.0
5	1	Yes	6		outside							10:20			
6	1	Yes	7		Living							14:35	2	0.1	2.0
7	1	Yes	8		Kitchen			17:30	00:10	14:35		17:15	1.2	0.1	1.2
8	1	Yes	9		Living	Room1	0.5	17:30	00:10	17:15		17:35	1.2	0.1	1.3
9	1	Yes	10		Kitchen			18:15	00:15	17:35		18:30	1.2	0.1	1.2
10	1	Yes	11		Living			18:50	00:10	18:30		18:40	1.2	0.1	1.0
11	1	Yes	12		Bath			19:00	00:15	18:40		19:00	1.2	0.1	1.3
12	1	Yes	999		Room1			19:10	00:15	19:00	23:59	19:20	1.2	0.1	1.1

Random values

Event	Hour	Metabol.
0.43	0.30	0.32
0.28	0.53	0.82
0.51	0.73	0.45
0.57	0.05	0.04
0.95	0.03	0.00
0.38	0.60	0.34
0.59	0.37	0.59
0.71	0.68	0.73
0.83	0.27	0.48
0.18	0.23	0.04
0.46	0.78	0.84
0.70	0.52	0.12

Occupant 5 - Week-end

Event	Probability	Yes or No?	Next YES	Next NO	Zone 1	Zone 2	Time in 1	Mean	Stdev	Min	Max	Hour	Met	Stdev	Metabol.
1	0.03	No	2	999	Living			19:30	00:30	19:50	20:50	20:00	4	0.2	3.9
2	1	Yes	999		outside			23:00	00:30	22:30	23:59	0.96			

Random values

Event	Hour	Metabol.
0.86	0.42	0.34
0.54	0.07	0.48

Figure 32: Setting up occupancy pattern for COMIS simulation with the "Occupancy schedules tool for COMIS – version 1" tool (continued)

Time	Zone ID	Acti-vity level	Number	Comment
20031001_00:00	Room2	0.8	1	# Sunday
20031001_08:05	Room2	0	0	# Sunday
20031001_08:05	Living	1.3	1	# Sunday
20031001_10:50	Living	0	0	# Sunday
20031001_14:35	Living	2.1	1	# Sunday
20031001_22:40	Living	0	0	# Sunday
20031001_22:40	Bath	1.1	1	# Sunday
20031001_23:20	Bath	0	0	# Sunday
20031001_23:20	Room2	1.2	1	# Sunday
20031002_06:20	Room2	0	0	# Monday
20031002_06:20	Bath	1.2	1	# Monday
20031002_06:35	Bath	0	0	# Monday
20031002_06:35	Kitchen	2.1	1	# Monday
20031002_06:40	Kitchen	0	0	# Monday
20031002_06:40	Living	2.1	1	# Monday
20031002_06:45	Living	0	0	# Monday
20031002_06:45	Kitchen	2.1	1	# Monday
20031002_06:50	Kitchen	0	0	# Monday
20031002_06:50	Living	2.1	1	# Monday
20031002_06:55	Living	0	0	# Monday
20031002_06:55	Kitchen	2.1	1	# Monday
20031002_07:00	Kitchen	0	0	# Monday
20031002_07:00	Living	2.1	1	# Monday
20031002_07:25	Living	0	0	# Monday
20031002_07:25	Kitchen	2.1	1	# Monday
20031002_07:45	Kitchen	0	0	# Monday
20031002_17:30	Living	1.9	1	# Monday
20031002_23:05	Living	0	0	# Monday
20031002_23:05	Bath	1.1	1	# Monday
20031002_23:15	Bath	0	0	# Monday
20031002_23:15	Room2	1.1	1	# Monday
...	...	...	…	...

Figure 33: Example of occupancy pattern file, as defined for COMIS

7.5.2 Building air tightness

As said in § 6.2.5, several parameters are required to simulate the building air tightness: the global air tightness expressed by its coefficient C and flow exponent n, the repartition of the cracks in the different rooms and the height of the cracks.

Which coefficient C and flow exponent n to use?

Several measurements were carried out on the IDEE house. After each measurement, the air tightness of the house was improved. These data show some link between C and n.

N°	n_{50} [h^{-1}]	C [m³/h@1Pa]	n [#]
1	10.3	200.6	0.63
2	6.2	83.2	0.72
3	4.6	89.6	0.62
4	4.4	64.0	0.70
5	3.2	51.3	0.68
6	2.4	18.0	0.87
7	2.1	16.1	0.86
8	1.7	10.9	0.91

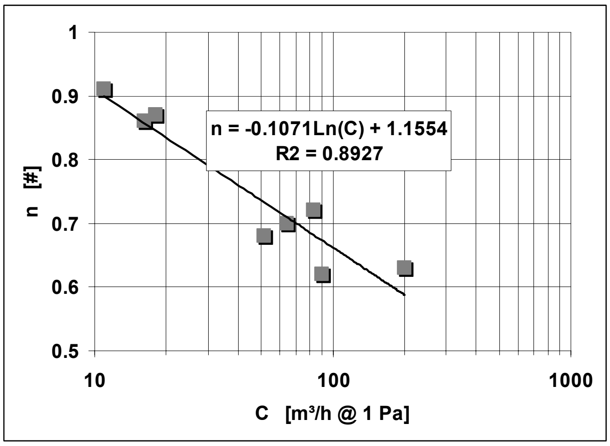


Table 9: Air tightness measurements of the IDEE house

To some extent, these measurements are in line with the values given in AIVC Technical Note 44. Originally, the air tightness is very low (n_{50} = 10.3 h^{-1}) and the flow exponent (0.63) corresponds to the value given for joints (0.63). When all joints are sealed, the air tightness has dramatically been improved (n_{50} = 1.7 h^{-1}) and the flow exponent (0.91) corresponds to almost laminar flow in porous material.

Which distribution of the cracks in the different rooms to use?

Annex 27 proposes to distribute the building leakage in proportion to the room floor areas. This choice is arguable, because the leakages take place on the external walls. It would have been more appropriate to distribute the building leakage in proportion to external wall areas - but this does not consider the leakages to the roof.

For the IDEE house, the distribution would be:

Repartition according to	Living	Room 1	Room 2	Hall 1	Kitchen	Bath-room	WC
floor area	34%	15%	20%	7%	15%	7%	2%
external wall area	27%	19%	22%	10%	11%	6%	5%

Table 10: Repartition of the global air tightness

Which height of the cracks to use?

It is also important to define the height at which the cracks are supposed to be in the façade. Annex 27 proposed to locate half of the cracks at 0.625 m from the floor and the other half at 1.875 m from the floor (assuming a room height of 2.5 m). In case of leaky buildings ($_{n50} \geq 10\ h^{-1}$), additional cracks should be located at the floor and at the ceiling.

How to simulate the building air tightness in COMIS?

In COMIS, the global building air tightness is defined as a crack type. The air mass flow coefficient Cs is given in kg/s @1 Pa. For instance, a n_{50} of 5.45 h^{-1} corresponds to an airflow of 1241 m³/h @ 50 Pa, or 89.6 m³/h @ 1 Pa (assuming a flow exponent of 0.67) or 0.03 kg/s @ 1 Pa.

&-CR Cracks						
| 1	*CR<name>	Description				
| 2	Cs	Exp n	Length	Wall properties		
|				Thickness	U-value	
|	(kg/s@1Pa)	(-)	[m]	[m]	[W/m²K]	
| 3	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	
|	(-)	(-)	(-)	(-)	(-)	
	*CR_n50	Global air tightness of the building - to be split among all cracks…				
	0.0300	0.67	100	d	d	
	0					

Figure 34: Global building air tightness of the IDEE house ($n_{50} = 5\ h^{-1}$) simulated in COMIS

The length of the crack representing the global air tightness is supposed to be 100 m (for 100%). The repartition among the different walls will be done by introducing a multiplication factor (as in Table 10) in the &-NET-LINK block.

&-NET-LINKs

|	Link ID	Airflow component ID	Zone ID		Height		Own height factor	Factor / Actual RPM / Value	3D flow or pressure	Sched.ID or Link-ID of RF or T-junction	
|			From	To	From	To					
|	(-)	(-)	(-)	(-)	[m]	[m]	[-]	[-]	[Pa]	[-]	
	Lcr1.1	CR_n50	-EX_E	Hall1	1.875	1.875	d	5.3			
	Lcr1.2.1	CR_n50	-EX_E	Living	1.875	1.875	d	6.0			
	Lcr1.2.2	CR_n50	-EX_S	Living	1.875	1.875	d	7.6			
	Lcr1.3	CR_n50	-EX_S	Bath	1.875	1.875	d	2.7			
	Lcr1.4.1	CR_n50	-EX_S	Room2	1.875	1.875	d	5.0			
	Lcr1.4.2	CR_n50	-EX_W	Room2	1.875	1.875	d	6.0			
	Lcr1.5.1	CR_n50	-EX_W	Room1	1.875	1.875	d	3.6			
	Lcr1.5.2	CR_n50	-EX_N	Room1	1.875	1.875	d	5.8			
	Lcr1.6	CR_n50	-EX_N	Kitchen	1.875	1.875	d	5.4			
	Lcr1.7	CR_n50	-EX_N	WC	1.875	1.875	d	2.5			
	Lcr2.1	CR_n50	-EX_E	Hall1	0.625	0.625	d	5.3			
	Lcr2.2.1	CR_n50	-EX_E	Living	0.625	0.625	d	6.0			
	Lcr2.2.2	CR_n50	-EX_S	Living	0.625	0.625	d	7.6			
	Lcr2.3	CR_n50	-EX_S	Bath	0.625	0.625	d	2.7			
	Lcr2.4.1	CR_n50	-EX_S	Room2	0.625	0.625	d	5.0			
	Lcr2.4.2	CR_n50	-EX_W	Room2	0.625	0.625	d	6.0			
	Lcr2.5.1	CR_n50	-EX_W	Room1	0.625	0.625	d	3.6			
	Lcr2.5.2	CR_n50	-EX_N	Room1	0.625	0.625	d	5.8			
	Lcr2.6	CR_n50	-EX_N	Kitchen	0.625	0.625	d	5.4			
	Lcr2.7	CR_n50	-EX_N	WC	0.625	0.625	d	2.5			

Figure 35: Example of leakage distribution of the IDEE house simulated in COMIS

How to implement the aspects related to building air tightness in the Monte-Carlo process?

1) C and n

On basis of the **measurements** carried out in the IDEE house, a **distribution of the airflow coefficient C** has been determined. The airflow exponent n is deducted from the C coefficient, according to the extrapolation given in Table 9.

C follows a Normal distribution with an average value of 89.58 m^3/h@1Pa and a standard deviation of 40, but with minimum and maximum values of 10.90 and 200.60 m^3/h@1Pa. This corresponds to a n_{50} value that follows a Normal distribution with an average value of 5.45 h^{-1}, but with minimum and maximum values of 1.65 and 9.19 h^{-1}.

2) Height of the cracks

The cracks are distributed over the wall height. Three options are defined, with a probability of 1/3 each: one crack at 1.4 m, two cracks at 0.625 and 1.875 m (as proposed by Annex 24) or 3 cracks at 0.47, 1.4 and 2.33 m.

7.5.3 Indoor temperatures

As COMIS is a ventilation model only, the indoor temperatures can not be calculated (excepted if COMIS is coupled with e.g. TRNSYS) but have to be defined by a constant, a schedule or a file. In the current simulation, it was decided to fix the same temperature in the whole building, but to introduce this indoor temperature as a stochastic parameter.

In COMIS, the room are described in the &-NET-ZONEs block by a temperature (as a constant or a schedule), a reference height, a volume and a absolute humidity level.

&-NET-ZONEs

|	Zone ID	Description	Temperature	Reference height	Volume [m³] or	Absolute humidity	Schedule name
|	(-)	[-]	[C]	[m]	H/D/W [3*m]	[g/kg]	[-]
	Hall1	Hall1	20	0	15.8	d	
	Living	Living	20	0	72.9	d	
	Bath	Bath	20	0	15.4	d	
	Room2	Room2	20	0	43.2	d	
	Room1	Room1	20	0	32.0	d	
	Kitchen	Kitchen	20	0	31.6	d	
	WC	WC	20	0	4.9	d	
	Hall2	Hall2	20	0	11.9	d	
#				Total volume =	227.7	m³	

Figure 36:Definition of room of the IDEE house, as well as their indoor temperature

7.6 ANALYSIS OF MAIN RESULTS OF THE COMIS SIMULATIONS

In the current example, three type of analysis have been carried out with the results of each simulation run: the average airflow rate of outdoor air that comes in the whole building, the energy loss due to ventilation and the exposure to CO_2 for each occupant.

7.6.1 Airflow rate of outdoor air

Figure 37 presents the average airflow rate of outdoor air for both systems C and H; this output is directly calculated by COMIS (output "IB").

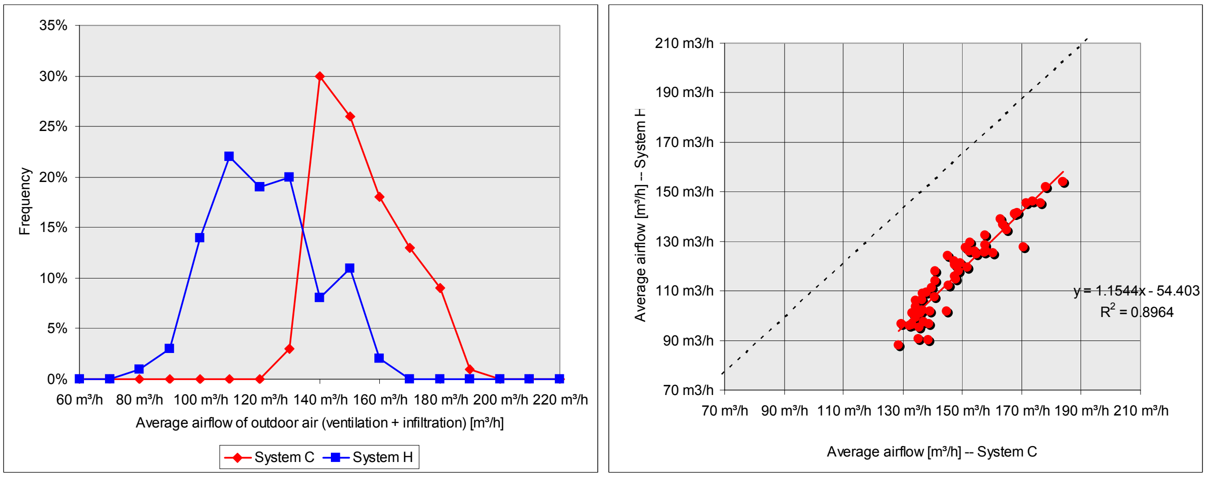


Figure 37: Average airflow rate of outdoor air (ventilation and infiltration)

From Figure 37, it can be seen that:

- the average airflow rates of outdoor air for systems C and H are 149 m³/h and 117 m³/h respectively,
- the spread around this mean value is higher for system H (79-154 m³/h) than for system C (128-184 m³/h), because the airflow is influenced by the occupancy in case of system H and not in case of system C,
- the ratio between the airflow rates of systems H and C varies between 61% and 88%,
- in average, the ratio between the airflow rates of systems C and H is 78%, whereas it was 84% for the first simulation.

7.6.2 Energy loss due to ventilation

Figure 38 presents the ventilation losses due to ventilation and infiltration for both systems C and H; this output is directly calculated by COMIS (output "LB").

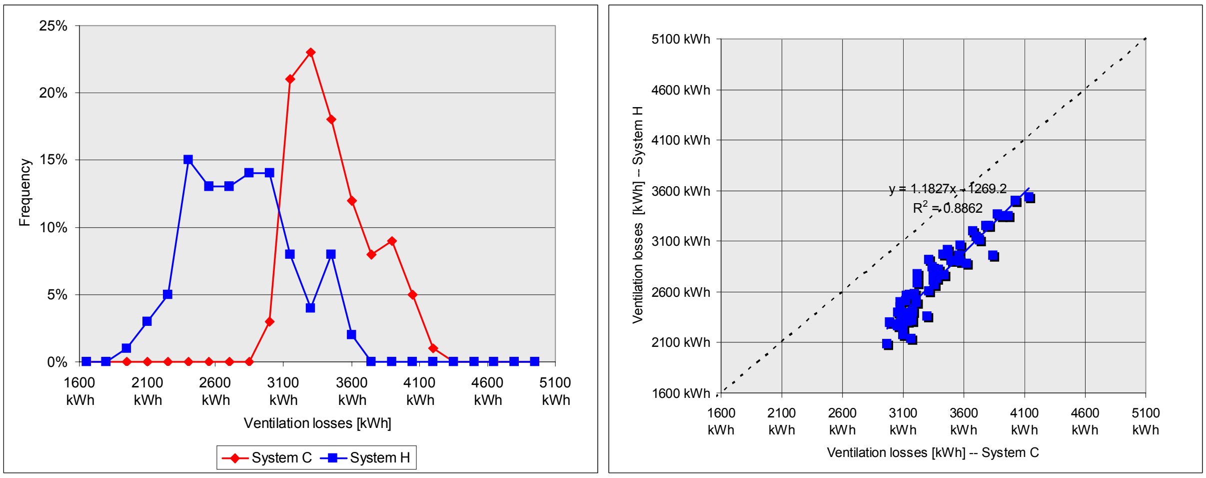


Figure 38: Ventilation losses

From Figure 38, it can be seen that:

- the average ventilation losses for systems C and H are 3385 kWh and 2720 kWh respectively,
- the spread around this mean value for systems C and H are (2966-4139 kWh) and (1910-3532 kWh) respectively,
- the ratio between the ventilation losses of systems C and H is between 63% and 89%,
- in average, the ratio between the ventilation losses of systems H and C is 80%, whereas it was 86% for the first simulation; in this specific case, the Probabilistic Approach analysis gives a better performance for system H than a single simulation run, because the average occupancy for the 100 sets is 2.9 person, whereas it is 4 for the first simulation.
- there is (obviously) a relationship between the ventilation losses and the average airflow rates of outdoor air.

7.6.3 Exposure to CO_2 for each occupant

This output is calculated according to the French criteria. The cumulative CO_2 concentration above 2000 ppm is calculated for each occupant. The French regulation requires that the cumulative CO_2 concentration stays below 500.000 ppm.hours.

A macro has been written in Excel in order to calculate this. This macro uses the "On-S room_x" and "Cn-S room_x" outputs from COMIS. The first one gives the number of occupants of type n that are present in room_x for every time step. The second one gives the concentration of pollutant n in room_x for every time step.

The "perfect" hybrid ventilation system should at the same time maintain the IAQ at an acceptable level and reduce the airflow as much as possible during heating season, in order to reduce energy. Such "perfect" would therefore try to maintain the cumulative CO_2 concentration just at the limit of 500 kppm.hours, whatever the climatic conditions, as illustrated in Figure 39. This is of course not possible in practice, as the occupancy and weather conditions can not be known in advance; however, Figure 39 shows the tendency that a hybrid ventilation system should follow.

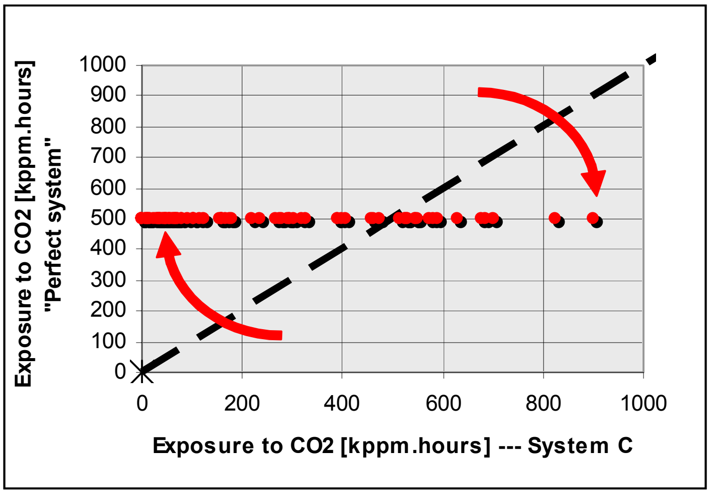


Figure 39:"Perfect" hybrid system

From Figure 40, it can be seen that:

- the French criteria is respected for both systems C and H,
- the system H simulated in this study is far from being "perfect"; there is still a lot of energy potential for energy savings. A system controlled by CO_2 would probably perform much better.

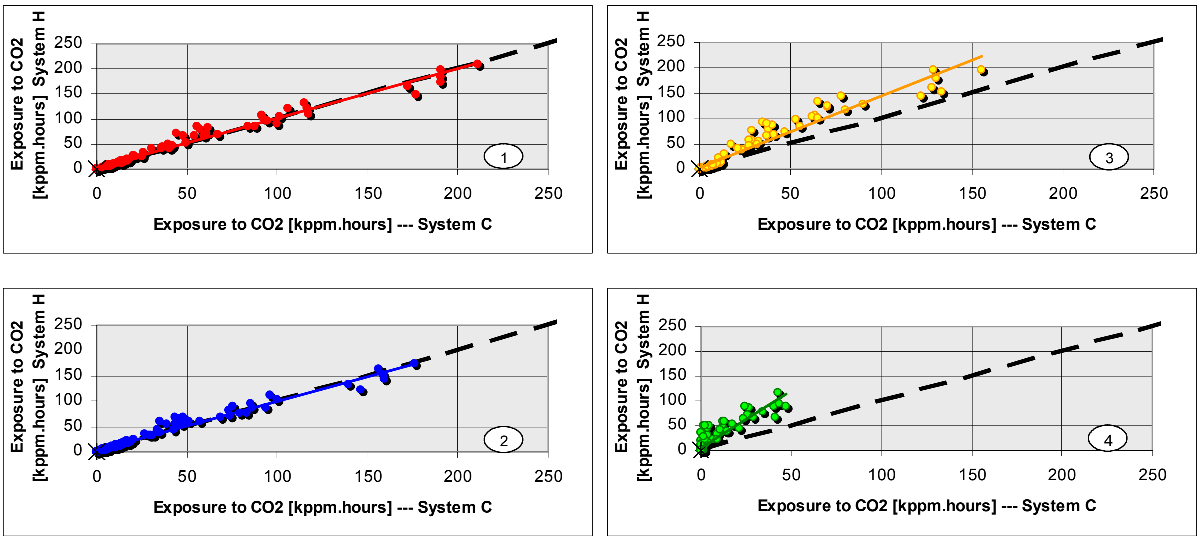


Figure 40: Exposure to CO_2 – systems C and H

7.6.4 Impact of the building air tightness

The impact of the building air tightness (n_{50}) was evaluated by a sensitivity analysis, as well as the impact of the number of cracks in each wall (see page 3). For these sensitivity analyses, the number of occupants has been fixed at 4 persons.

- Figure 41 shows that the average airflow rate and the energy consumption for ventilation are very dependant of the global air tightness of the dwelling (n_{50}).
- Figure 42 shows that the results are not influenced too much by the number of cracks introduced in each wall to simulate the leaks; this however can be different for a building with more than 1 storey, and with a ventilation system controlled by CO_2.

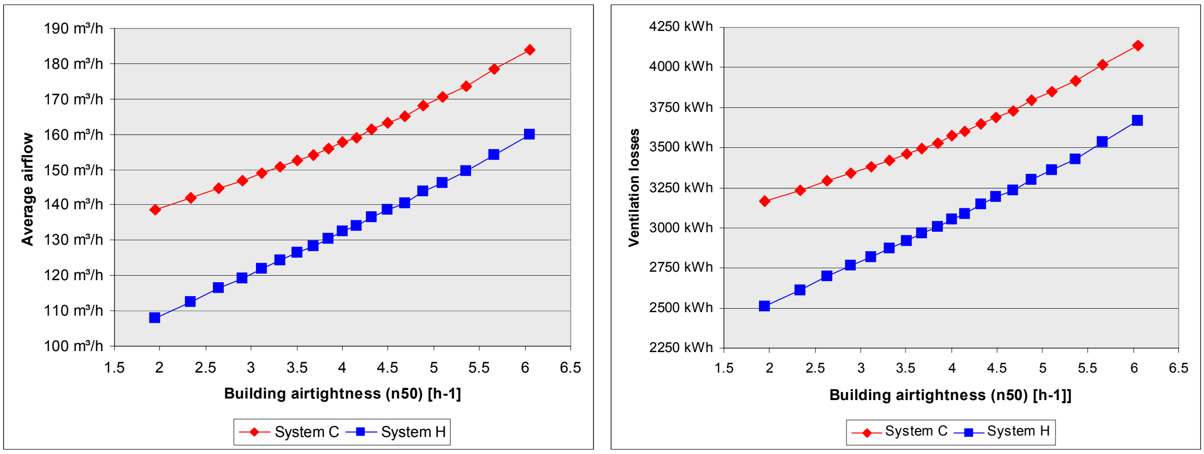


Figure 41: Impact of the building air tightness (n_{50})

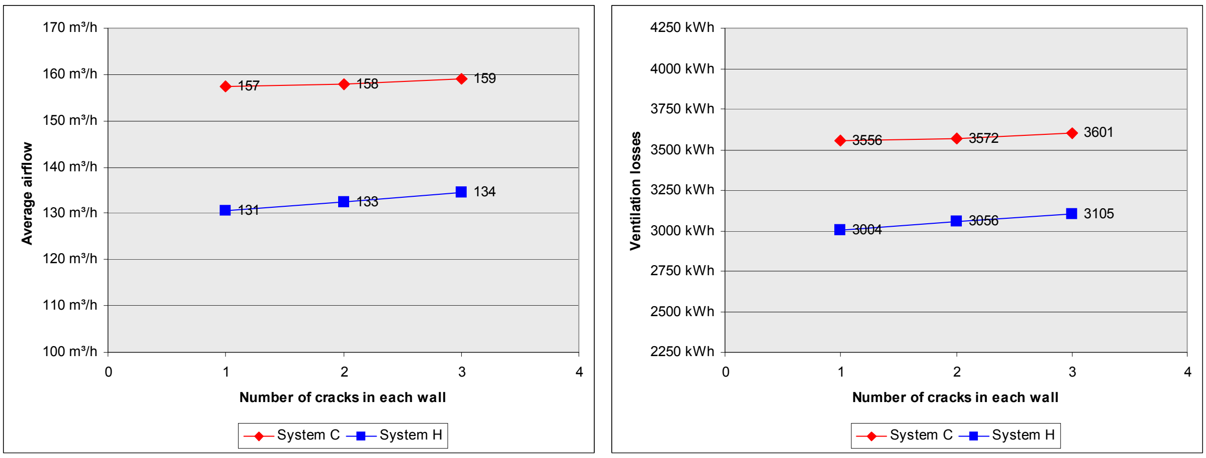


Figure 42: Impact of the number of cracks in each wall (1, 2 or 3)

7.6.5 Impact of the occupancy

The impact of the occupancy was evaluated by running a Monte-Carlo analysis, where only the occupancy related parameters varied stochastically.

Figure 43 shows the average airflow rates, the ventilation losses and the number of occupants, for the 100 occupancy profiles (the order has been modified to show increasing airflow rates).

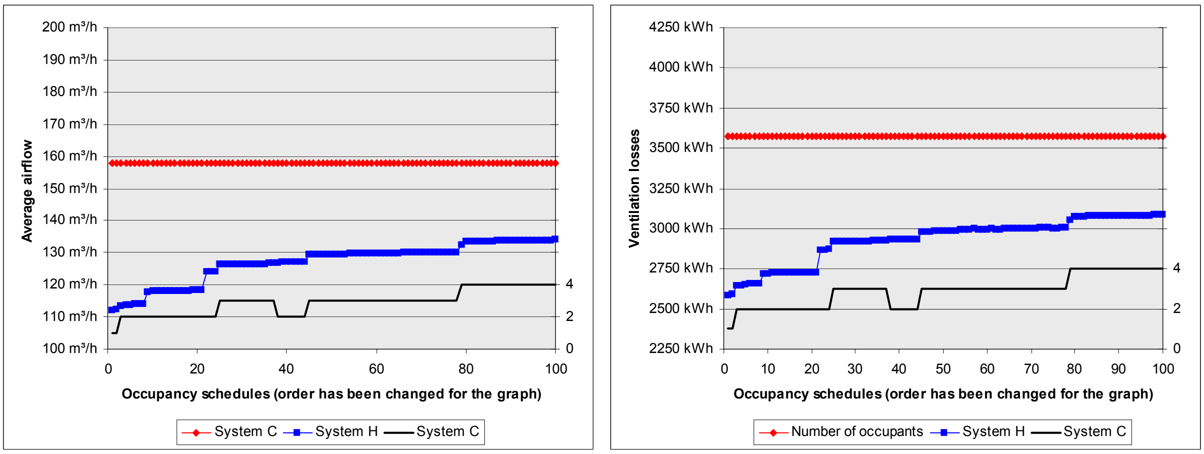


Figure 43: Impact of the occupancy

7.6.6 Impact of the wind shielding conditions

The impact of the building wind shielding conditions was evaluated by a sensitivity analysis.

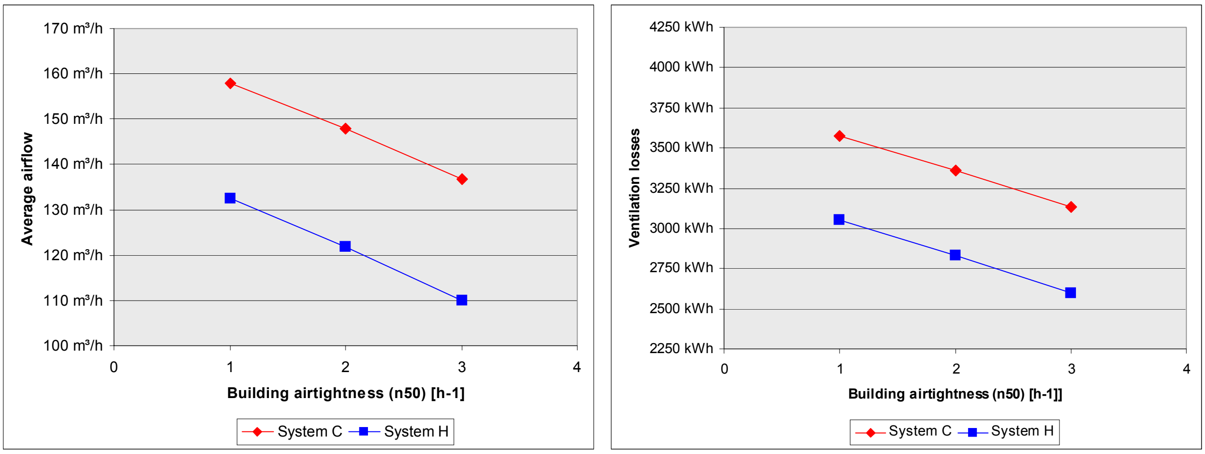


Figure 44: Impact of the wind shielding conditions

7.7 CONCLUSIONS

The simulations have shown that:

- With COMIS and an Excel sheet, it is technically possible to apply a Monte-Carlo approach which is entirely automated[12], including the analysis of the results.
- For the specific case analysed, the benefit of using system H instead of system C varies between 11% to 37%. This clearly shows that the boundary conditions should not be chosen by the person in charge of the PoE analysis (he would of course chose those that increase the energy savings), but should be fixed by the authorities.
- The impact of some of the assumptions has been highlighted thanks to the sensitivity analyses. In the specific case analysed, the global building air tightness (n_{50}), the occupancy and the wind shielding conditions have a great impact on the performances of the systems; the number of cracks in each room has a limited impact. This show that a great care must be taken when selecting the input data. This also shows that a Probabilistic Approach will give more realistic results than running a single simulation.

[12] This was already possible with the COMISexcel tool developed by Peter Schild. The generation of the input data is somewhat different in this tool.

Part 3: Conclusions

8 CONCLUSIONS

8.1 NEED FOR A MIXTURE OF EUROPEAN AND NATIONAL APROACHES

The Energy Performance of Building Directive (EPBD) requires all Member States to implement Energy Performance of Building regulations. The EPBD only gives the main parameters that the EPB calculation procedures should include, but the actual development of the procedures is to a large part let to the responsibility of the Member States. Consequently, the procedures could vary considerably from one country to the other.

A whole range of innovative systems are at present not covered by the existing or coming EPB regulation procedures. As the market is in a wide scale driven by the regulations, this is a major barrier to innovation. Another barrier to the free circulation of products is that (innovative) systems will not be treated uniformly throughout the EU.

To have a successful implementation of the EPBD and, even more important, to actually save energy in buildings (which are responsible for ±40% of the final energy consumption in EU), these barriers to innovation should be removed. To achieve this objective, a framework for the assessment of innovative system must be set up in each Member State. (Note: a market transformation would also strengthen the competitiveness of European industries in the field of energy efficiency technologies and renewables.)

However, an optimal implementation is far from evident and certainly not cost-effective if national efforts are not combined and if Member States do not seize the opportunity to benefit from a mutual exchange of national experiences.

Taken into account the considerations mentioned before, it seems useful and even necessary (at least on the medium term) to have a mixture of European and national activities. This is illustrated in Figure 45.

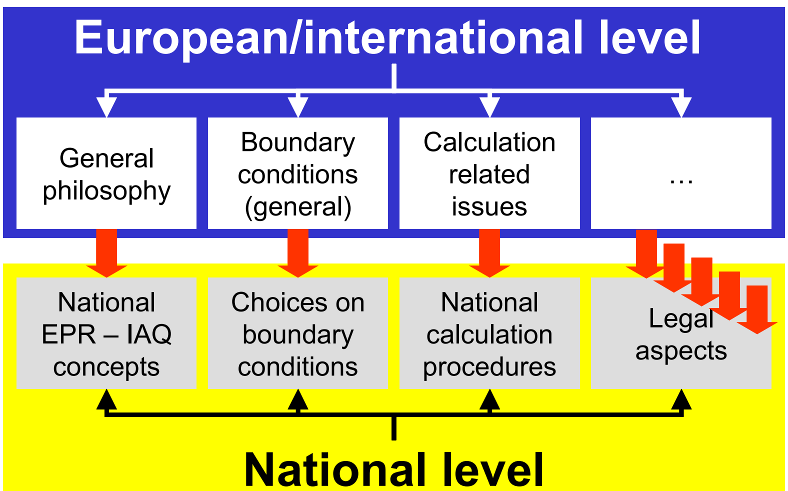


Figure 45: Combination of activities at European and national level

8.2 GENERAL PHILOSOPHY FOR PERFORMANCE ASSESSMENT

Without a framework for the assessment of the innovative systems, the EPBD is a barrier for innovation and for energy savings in buildings. But it would also be damageable for energy savings if the framework is so open that anyone can overestimate the performances of an so-called innovative system.

The general framework described in this report is believed to prevent this problem. The focus in this report has been mainly turned towards the evaluation of innovative ventilation systems. The general philosophy remains valid for every innovative system even if differences can be recorded. In summary, the philosophy is the following:

1. The "authorities" should identify all relevant parameters that might influence the performances of innovative (ventilation) systems (in this context, "authorities" means the CEN and the Member States).

2. The authorities should identify for all relevant parameters a probability distribution and…

3. … should create a substantial large number of data sets randomly (typically 100).

4. The person who carry the assessment should use an appropriate calculation model for assessing the performances of a building with a given ventilation system.

5. He should evaluate the performances of the various ventilation systems for the 100 datasets and…

6. … analyse the result in order to assess the performance of the various systems.

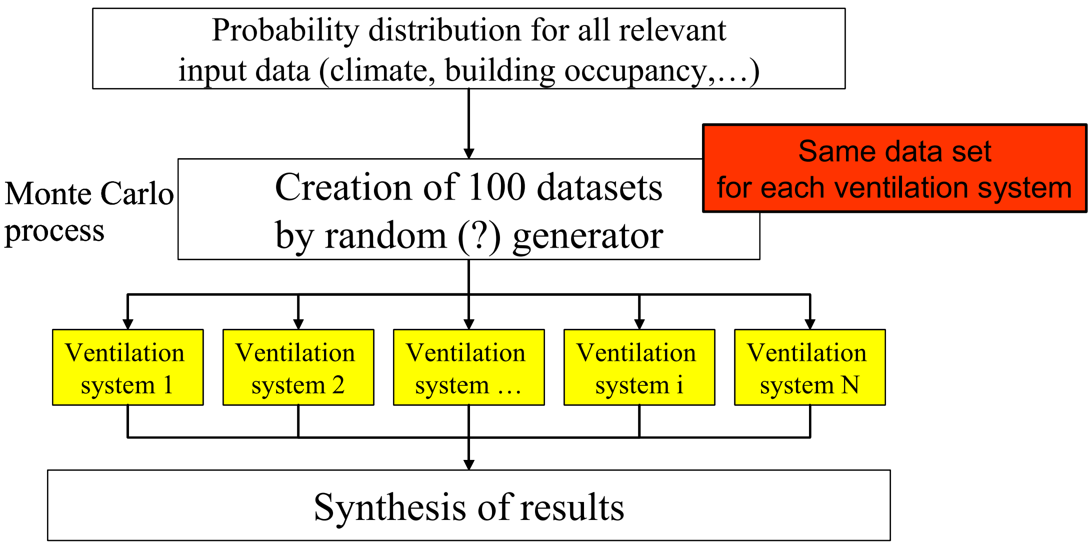


Figure 46: Philosophy of probabilistic performance prediction

The example presented in this report has shown that this procedure is feasible, and can be automated[13]. One could argue that carrying out 100 simulations takes time, but this is

[13] The model used in this report has been carried out in COMIS, but another model has been developed in TRNSYS+COMIS by IDMEC (WP6).

computer time which is not so costly as it does not require much of human intervention. The time to carry out a Principle of Equivalence as it was done for the Dutch school described previously is believed to be mainly spent in the collection of the input data and to built the model. Despite the fact that the proposed procedure requires to run 100 simulations instead of 1, it will facilitate the task of the person in charge of the assessment, as the input data have to be made available to him by the "authorities".

It must be highlighted that the way to make the link between the results of the simulation and the national EPB regulations has not be discussed deeply into details within the framework of RESHYVENT, as this is very dependant on the national regulations. This point, as many others, has still to be clarified.

8.3 FURTHER WORKS

In order to prevent the EPBD to be a barrier for innovative systems, the work related to the performances assessment of such systems has to be continued. The general framework discussed in the present report has still to be developed to bring it into an operational stage, and especially to generalise it to other innovative systems than ventilation systems[14].

The authors believe that the EC should give a mandate to CEN for developing a new standard on this topic. This standard (or technical report) should at least describe the general framework for the assessment, specify a list of input data that should be defined at national level and make proposals for them, in case the Member States do not have better values, and should be completed by national annexes.

[14] For this purpose, an European project proposal entitled INNOVET has been submitted in the context of the SAVE 2003 call for proposals, but it was unfortunately not accepted.

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ANNEX 1   COMIS MODEL OF THE IDEE HOUSE

The COMIS model of the IDEE house that has been used in this report is given in an MS Excel workbook available on the RESHYVENT cd-rom:
RESHYVENT-WP4-D43-PROBABILISTIC_APPROACH.annexes.zip > IDEEc.xls.

ANNEX 2 IMPLEMENTATION OF THE MONTE-CARLO PROCESS

The Monte-Carlo process has been implemented in a MS Excel sheet. This sheet will be explained in this paragraph. It must be noticed that this is only an example, and should not be considered as the only possible way.

A2.1.1 Sheet "Info"

The sheet "Info" contains some instructions on how to use the workbook, as well as three cells that have to be completed before to run any simulation, with the paths to the data (for the schedules), to the COMIS program and to a text editor program as e.g. wordpad.exe.

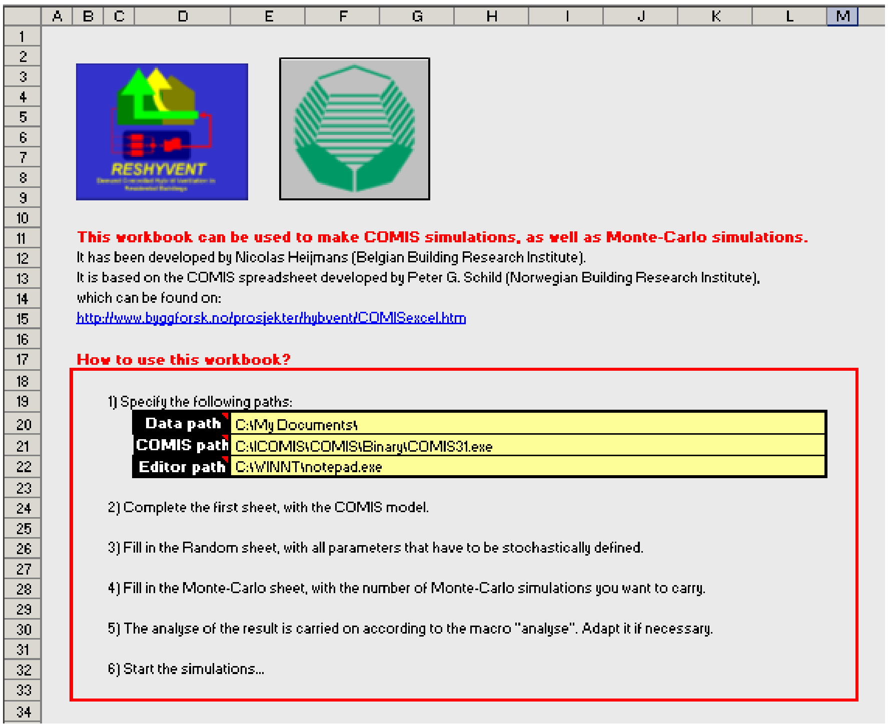


Figure 47: Sheet "Info"

A2.1.2 First sheet: the COMIS model

The first sheet, based on the "COMISexcel" user interface developed by Peter G. Schild., includes the COMIS model.

This sheet must necessary be the first one and includes a button to perform one simulation.

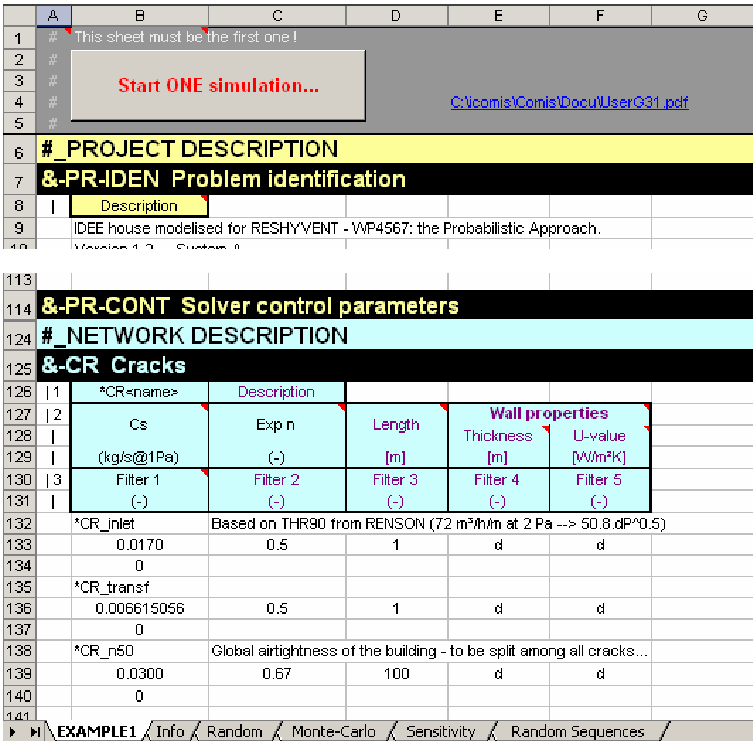


Figure 48: First sheet: the COMIS model.

A2.1.3 Sheet "Random"

The random process takes place in the sheet "Random". Firstly, the parameters that are part of the Monte-Carlo process are defined in the column C to J. Four types of functions are currently introduced (Interval, Normal distribution, Triangle, Series) but any other function can be defined by changing the formula in column L (see cells L10 and L13). Default values are defined in column J, rounding rules in column E and minimum/maximum values in column F to I, according to the function type.

During the calculations, random value will be written in column N and the results will be calculated in column L. Links to these cells are defined in the model sheet (see Figure 50).

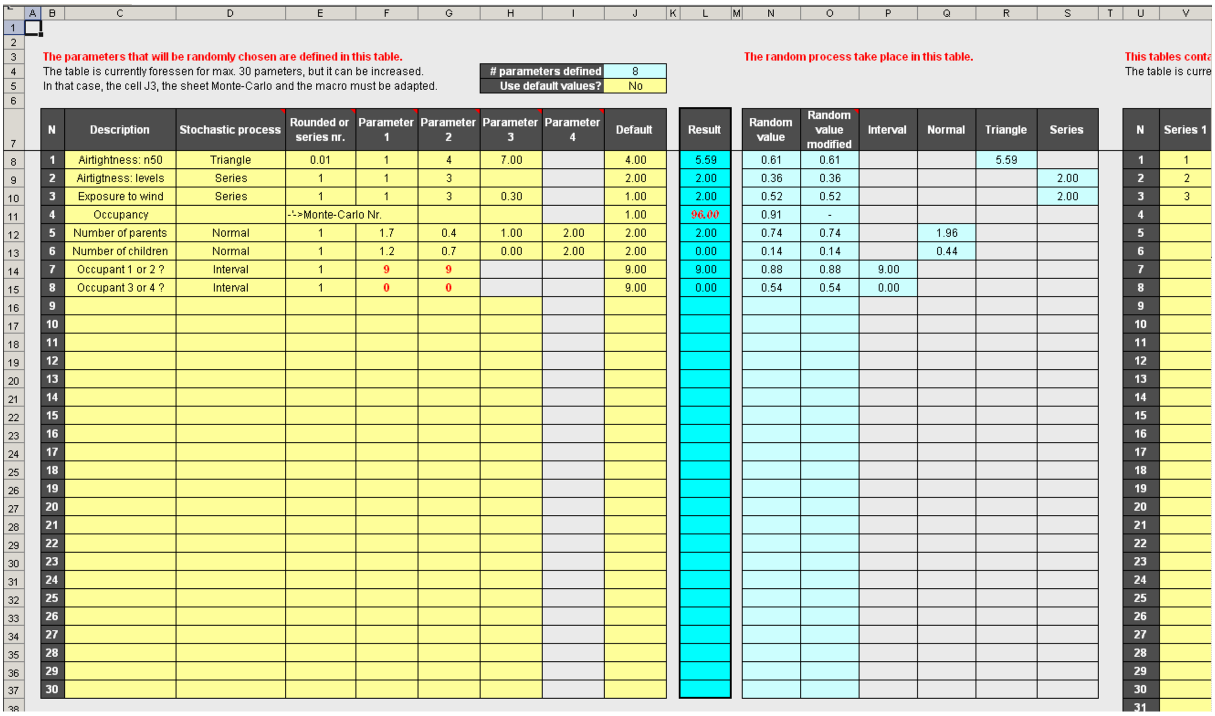


Figure 49: Sheet "Random"

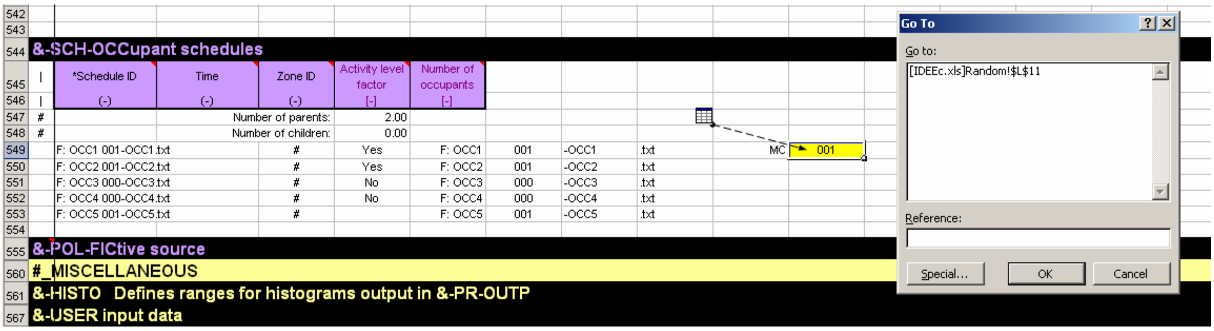
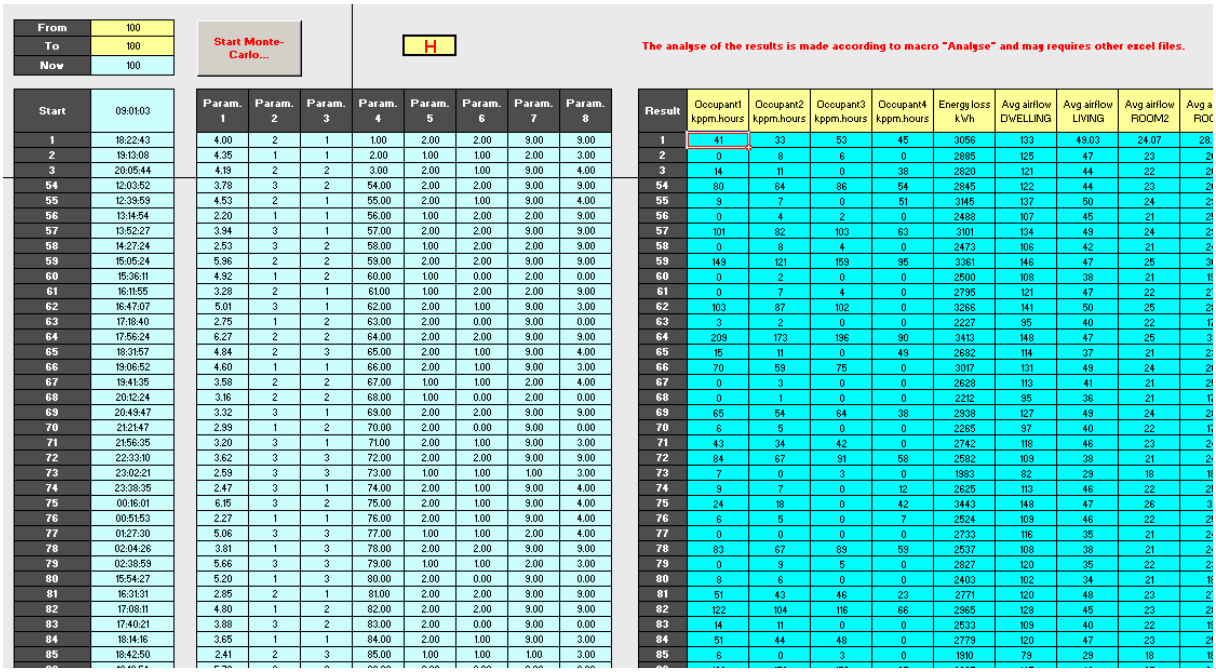


Figure 50: Link to sheet "Random" in the COMIS model

A2.1.4 Sheets "Monte-Carlo" and "Sensitivity"

All the data that were actually used in the Monte-Carlo process, as well as the results of the simulations, are given in the sheet "Monte-Carlo".



From	100
To	100
Now	100

Start Monte-Carlo...

H

The analyse of the results is made according to macro "Analyse" and may requires other excel files.

Start	09:01:03	Param. 1	Param. 2	Param. 3	Param. 4	Param. 5	Param. 6	Param. 7	Param. 8
1	18:22:43	4.00	2	1	1.00	2.00	2.00	9.00	9.00
2	19:13:08	4.35	1	1	2.00	1.00	1.00	2.00	3.00
3	20:05:44	4.19	2	2	3.00	2.00	1.00	9.00	4.00
54	12:03:52	3.78	3	2	54.00	2.00	2.00	9.00	9.00
55	12:39:59	4.53	2	1	55.00	2.00	1.00	9.00	4.00
56	13:14:54	2.20	1	1	56.00	1.00	2.00	2.00	9.00
57	13:52:27	3.94	3	1	57.00	2.00	2.00	9.00	9.00
58	14:27:24	2.53	3	2	58.00	1.00	2.00	2.00	9.00
59	15:05:24	5.96	2	2	59.00	2.00	2.00	9.00	9.00
60	15:36:11	4.92	1	2	60.00	1.00	0.00	2.00	0.00
61	16:11:55	3.28	2	1	61.00	1.00	2.00	2.00	9.00
62	16:47:07	5.01	3	1	62.00	2.00	1.00	9.00	3.00
63	17:18:40	2.75	1	2	63.00	2.00	0.00	9.00	0.00
64	17:56:24	6.27	2	2	64.00	2.00	2.00	9.00	9.00
65	18:31:57	4.84	2	3	65.00	2.00	1.00	9.00	4.00
66	19:06:52	4.60	1	1	66.00	2.00	1.00	9.00	3.00
67	19:41:35	3.58	2	2	67.00	1.00	1.00	2.00	4.00
68	20:12:24	3.16	2	2	68.00	1.00	0.00	2.00	0.00
69	20:49:47	3.32	3	1	69.00	2.00	2.00	9.00	9.00
70	21:21:47	2.99	1	2	70.00	2.00	0.00	9.00	0.00
71	21:56:35	3.20	3	1	71.00	2.00	1.00	9.00	3.00
72	22:33:10	3.62	3	3	72.00	2.00	2.00	9.00	9.00
73	23:02:21	2.59	3	3	73.00	1.00	1.00	1.00	3.00
74	23:38:35	2.47	3	1	74.00	2.00	1.00	9.00	4.00
75	00:16:01	6.15	3	2	75.00	2.00	1.00	9.00	4.00
76	00:51:53	2.27	1	1	76.00	2.00	1.00	9.00	4.00
77	01:27:30	5.06	3	3	77.00	1.00	1.00	2.00	4.00
78	02:04:26	3.81	1	3	78.00	2.00	2.00	9.00	9.00
79	02:38:59	5.66	3	3	79.00	1.00	1.00	2.00	3.00
80	15:54:27	5.20	1	3	80.00	2.00	0.00	9.00	0.00
81	16:31:31	2.85	2	1	81.00	2.00	2.00	9.00	9.00
82	17:08:11	4.80	1	2	82.00	2.00	2.00	9.00	9.00
83	17:40:21	3.88	3	2	83.00	2.00	0.00	9.00	0.00
84	18:14:16	3.65	1	1	84.00	2.00	1.00	9.00	3.00
85	18:42:50	2.41	2	3	85.00	1.00	1.00	1.00	3.00

Result	Occupant1 kppm.hours	Occupant2 kppm.hours	Occupant3 kppm.hours	Occupant4 kppm.hours	Energy loss kWh	Avg airflow DWELLING	Avg airflow LIVING	Avg airflow ROOM2
1	41	33	53	45	3056	133	49.03	24.07
2	0	8	6	0	2885	125	47	23
3	14	11	0	38	2820	121	44	22
54	80	64	86	54	2845	122	44	23
55	9	7	0	51	3145	137	50	24
56	0	4	2	0	2488	107	45	21
57	101	82	103	63	3101	134	49	24
58	0	8	4	0	2473	106	42	21
59	149	121	159	95	3361	146	47	25
60	0	2	0	0	2500	108	38	21
61	0	7	4	0	2795	121	47	22
62	103	87	102	0	3266	141	50	25
63	3	2	0	0	2227	95	40	22
64	209	173	196	90	3413	148	47	25
65	15	11	0	49	2682	114	37	21
66	70	59	75	0	3017	131	49	24
67	0	3	0	0	2628	113	41	21
68	0	1	0	0	2212	95	36	21
69	65	54	64	38	2938	127	49	24
70	6	5	0	0	2265	97	40	22
71	43	34	42	0	2742	118	46	23
72	84	67	91	58	2582	109	38	21
73	7	0	3	0	1983	82	29	18
74	9	7	0	12	2625	113	46	22
75	24	18	0	42	3443	148	47	26
76	6	5	0	7	2524	109	46	22
77	0	0	0	0	2733	116	35	21
78	83	67	89	59	2537	108	38	21
79	0	9	5	0	2827	120	35	22
80	8	6	0	0	2403	102	34	21
81	51	43	46	23	2771	120	48	23
82	122	104	116	66	2965	128	45	23
83	14	11	0	0	2533	109	40	22
84	51	44	48	0	2779	120	47	23
85	6	0	3	0	1910	79	29	18

Figure 51: Sheet "Monte-Carlo"

There is a similar sheet for the sensitivity analysis.

A2.1.5 Sheet "Random sequences"

The random sequences that were actually used in the Monte-Carlo process are the one give in the sheet "Random sequences". New sequences can be generated by pressing the button.

In contrary to the sequences generated by Sobol's algorithm, the sequences contain 100 values only and are uniformly distributed between 0 and 1.

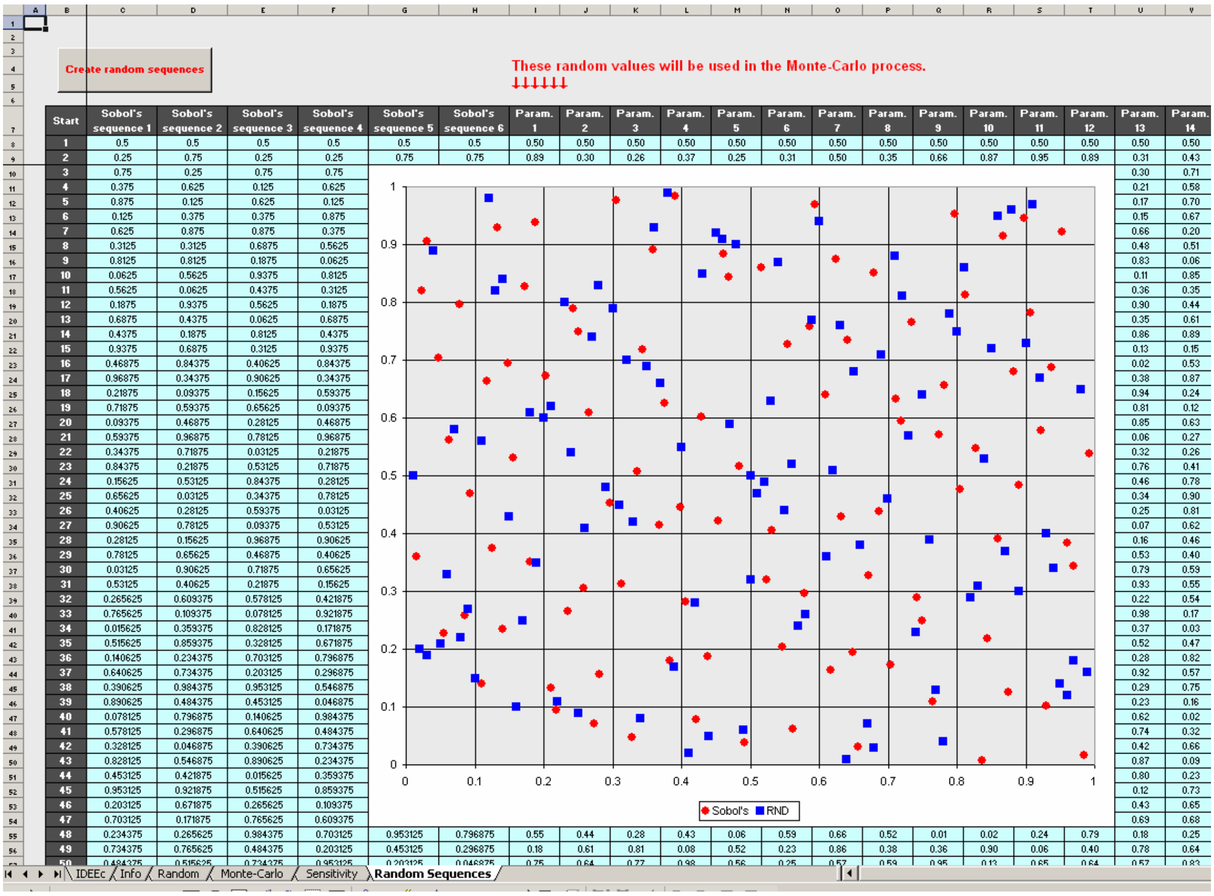


Figure 52: Sheet "Random sequences"

ANNEX 3 OCCUPANCY SCHEDULES TOOL FOR COMIS

In order to simplify the process of creating stochastic occupancy patterns for COMIS, a dedicated tool has been developed by BBRI in MS Excel. The first version of this tool is shortly presented below.

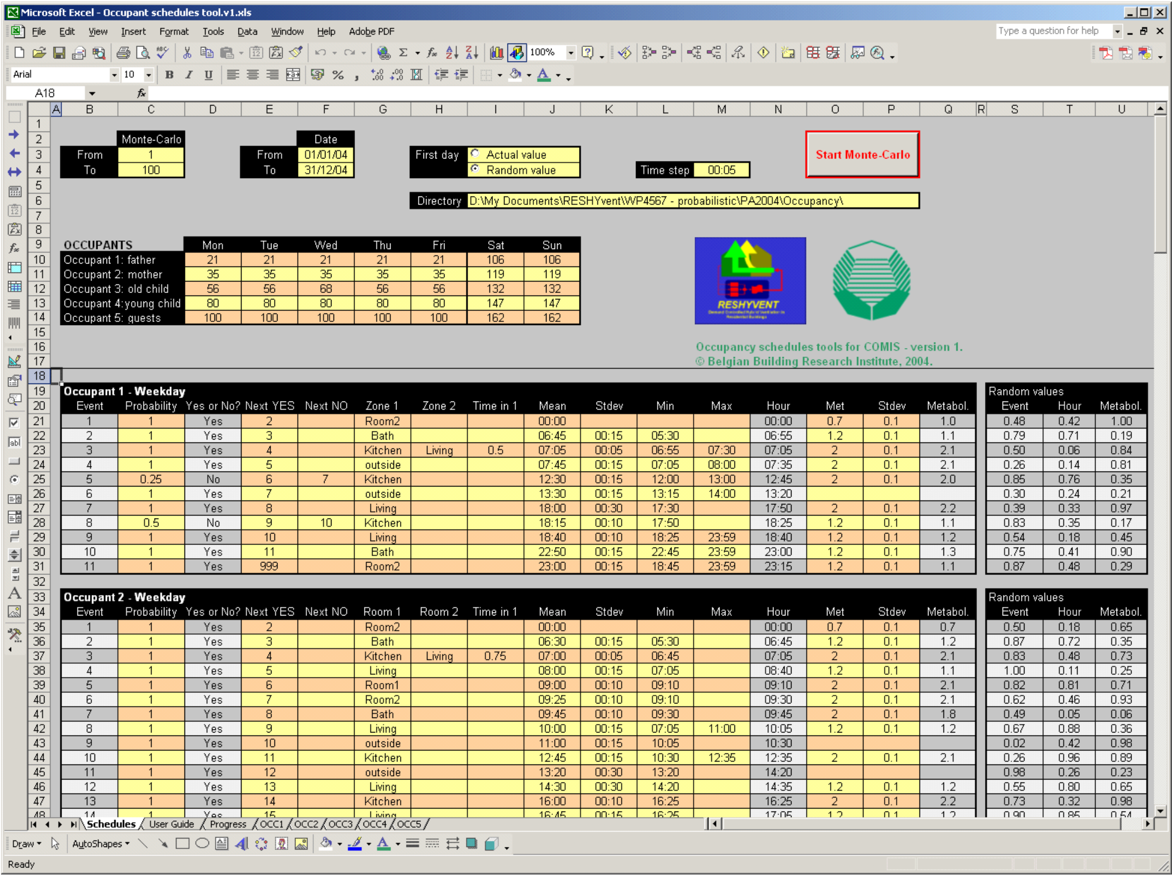


Figure 53: Occupancy schedules tool for COMIS – version 1

The coloured cells have to be filled by the user. He can choose the number of patterns to produce, the start and end dates, if the first week day of the period is chosen according to its actual value or if it is randomly chosen, and the smallest time step. He must specify at which average time an occupant enters a zone, as well as the standard deviation around this date, and possibly a minimum and a maximum time, as well as the probability that this event occurs. He can also specify that the occupant will spent his time between two zones. He must finally specify the average metabolism rate and its standard deviation.

The visual basic subroutine will give for each day and each occupant some random values to determine if the event occurs, at which time and with which metabolism rate. For the moment, the time and the metabolism are determined according to a normal distribution, but it is of course possible to change the function in the Excel sheet.

The main advantage of this tool is that is possible to change the probability of an event according to another event (for instance, if some people are invited for the dinner, the probability that the father helps his wife in the kitchen can be increased), or that events occur after other ones (for instance, the children will not go to the bathroom if the father has not left it). The tool could also be programmed so that the probability that an event occurs depends on what happened e.g. the day before.

The time required by a Pentium 4 computer to produce 100 one-year patterns for 5 occupants was about 1h25. This duration depends on the number of possible events defined for each occupant, and obviously on the computer.

In a second version, this tool could be developed so that window openings are related to occupancy, as well as to meteorological conditions.

The "Occupancy schedules tool for COMIS – version 1" is given in an MS Excel workbook available on the RESHYVENT cd-rom:
RESHYVENT-WP4-D43-PROBABILISTIC_APPROACH.annexes.zip >
Occupant schedules tool for COMIS.v1-7.xls.

RESHYVENT

Demand Controlled Hybrid Ventilation in Residential Buildings

RESHYVENT

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