UNCERTAINTIES IN DIFFERENT LEVEL ASSESSMENTS OF DOMESTIC VENTILATION SYSTEMS

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ABSTRACT

In order to improve the quality of ventilation systems, assessments are widely used. In this paper, 3 main assessment levels are distinguished based on the number of ventilation systems to be assessed and the assessment objective. The main assessment levels distinguished in this paper are **global leve**l (the assessment concerns a set of ventilation systems within a country or region), **project level** (the assessment concerns a set of ventilation projects within a housing project) and **design level** (the assessment concerns one ventilation system in a housing project for different environments and different types of occupants).
Uncertainties should be considered and dealt with in assessments of domestic ventilation systems. The uncertainties that determine the in use performance of a domestic ventilation system are present in four aspects, ventilation components, building properties, outdoor environment and occupants. The structure of the uncertainties in an assessment is further studied starting from two types of uncertainties (reducible and irreducible) to two levels of uncertainty data (basic level and mixed level data).
Two different methods how to deal with different assessment levels and their uncertainties are subsequently discussed as well as how to choose a method for a specific assessment level. The methods that are developed are the accurate method and the prototype method. Finally, a brief demonstration of the described concepts and methods is given.

KEYWORDS

Assessment, uncertainties, ventilation

1 INTRODUCTION

After the energy crisis in the 70s of the last century, people realized the importance of energy saving and reducing the energy lost due to fresh air exchange became crucial. People realized that it is important to provide a sufficient, but not excessive air exchange rate, i.e. air exchange should be more controllable and efficient in the domestic setting. To achieve this goal, a properly designed ventilation system in a house is required. In order to improve the quality of ventilation systems, assessment is widely used for evaluating the performance of domestic ventilation systems and consequently improving the design of the systems. In an assessment of a domestic ventilation system, the influence of uncertainties can play an important role. In the assessment of domestic ventilation system(s), uncertainties can come into existence during 3 stages: 1) variations in the design stage; 2) variations during the construction stage; 3) variations during the measurements of the performance. The uncertainties are present in the four aspects, ventilation components, building properties,

outdoor environment and occupants, that determine the in use performance of a ventilation system for a domestic ventilation system.
These uncertainties must be considered and dealt with in an assessment process. In this paper different assessment levels are defined and it is described how the uncertainties should be treated for these different assessment levels. An example is included at the end.

2 ASSESSMENT LEVELS

Domestic ventilation systems are assessed for many different purposes. We categorised these different purposes into 3 assessment levels, i.e. the global level, the project level and the design level. The global level is used when the assessment concerns a set of ventilation systems within a country or region. The project level is used when the assessment concerns a set of ventilation projects within a housing project. The design level assessment is used when the assessment concerns one ventilation system in a housing project for different environments and different types of occupants. Each of these 3 levels can be further divided into sub-levels, see table 1. The explanations of these sub assessment levels are given below, including the scale of each assessment level and the relevant assessment objective.

Table 1: Summary of Assessment Cases by Uncertain Design Parameters

	Uncertainties in design parameters, i.e. Reducible Uncertainties		
	all four aspects: - ventilation components - building components - outdoor environment - type of occupants	**system aspects:** - ventilation components and/ or - building components	**boundary aspects:** - outdoor environment and/ or - type of occupant
A: global level	uncertain (A1)	uncertain (A2)	uncertain (A3)
B: project level	uncertain (B1)	uncertain (B2)	uncertain (B3)
C: design level	uncertain (C1); certain (C4);	uncertain (C2)	uncertain (C3)

Assessment level A, **global level**:

- Case A1: The assessment objective is to gain an overview of the performance of the domestic ventilation systems in a country or a region. Case A1 can be used to assess whether the design regulations provide sufficient guidance or governance to achieve the wanted/ required performance of the ventilation system. The set of ventilation systems under assessment contains ventilation systems with different designs, i.e. different ventilation components, building components, outdoor environments, and types of occupants.
- Case A2: The assessment objective is to determine the overall design quality, or suitability of various types of ventilation systems regulated by the design regulations, for a specific environment and specific type of occupant.
- Case A3: The assessment objective is the suitability of a specifically designed ventilation system for a different environment and/or different occupants.

Assessment level B, **project level:**

- Case B1: The assessment objective is to gain an overview of the design quality or the performance of a set of ventilation systems in a housing project. The set of ventilation systems under assessment contains ventilation systems with different designs, i.e. different ventilation components, building components, outdoor environment, and occupants.

- Case B2: The assessment objective is to gain an overview of the expected performance of the designs of the set of ventilation systems in a housing project under a specific environment and/ or type of occupant.
- Case B3: The assessment objective is to obtain the suitability of a specific ventilation system in a housing project for different environments and different types of occupants.

Assessment level C, **design level:**

- case C1: The assessment objective is to determine the possible performance range, and the important design parameters for a ventilation system. The design parameters of the ventilation components, the building components, the outdoor environment and the occupants are uncertain.
- case C2: The assessment objective is to optimize the design. the design parameters of the ventilation components and/or the design of the building components are uncertain, the design parameters of the outdoor environment and the occupants are certain.
- case C3: The assessment purpose is to determine the suitability of a design for a specific environment or a specific set of occupants. The design parameters of the outdoor environment and/or the occupants are uncertain, the design parameters of the ventilation system are certain.
- case C4: The assessment purpose is to determine the expected performance of a specific ventilation design, and/or the quality/ influence of the construction/ installation process on a design. All the design parameters of the four aspects are certain, i.e. the design is definitive, and only the irreducible uncertainties need to be considered

3 STRUCTURE OF UNCERTAINTIES IN AN ASSESSMENT

3.1 Design parameters and input parameters

In each assessment we use two types of parameters, i.e. the design parameters and the input parameters. In each of the above mentioned 4 aspects, the design parameters and input parameters must be identified. Explanations for these two types of parameters are given below.

Before we carry out the assessment of a design for a domestic ventilation system, we need to determine the design parameters which will be used to specify the design. The design parameters are, in general, not suited to be used as input of the calculation model used for the assessment, which normally consists of a calculation model or a simulation model. Thus, the input parameters, which can be used as input for the calculation model, also need to be determined.

Design parameters are specified by the designer for any system, in our case a domestic ventilation system. The form of the input parameters used depends on the calculation model that will be used to calculate the performance of the ventilation systems. One important point is that the values of the input parameters and the uncertainties in these input parameters are actually determined or highly influenced by the design parameters.

3.2 Structure of the uncertainties

Having introduced the design parameters and input parameters, we can see that eventually we need to identify and/or estimate the uncertainties in the input parameters for the assessment.

We now define two types of uncertainties that can occur in an input parameter:

- Reducible uncertainty, this is the uncertainty which can be eliminated or reduced intentionally through more detailed design. A reducible uncertainty is the uncertainty in the design parameter which is caused by the design alternative or specification uncertainty.

- Irreducible uncertainty, this is the uncertainty which cannot be eliminated or reduced by a more specified design and which is caused by the limitations of our available knowledge or techniques, or the nature of the relevant parameter. The uncertainty caused by the construction/ production deviations, modeling uncertainties or scenario uncertainties are irreducible uncertainties.

3.3 Levels of uncertainties

The considerations and treatment methods for the uncertainties for each different level of assessment are not necessarily the same. When we look at table 1.1, it can be seen that, except for the C4 case, all other cases include, to different extents, uncertainties in the design parameters, i.e. reducible uncertainties. In other words, the uncertainties in the input parameters for the C4 case only include the irreducible uncertainties, and the uncertainties in the input parameters for all other cases are combinations of reducible uncertainties and irreducible uncertainties, as explained above. This led us to come up with the concept "level of uncertainty data". This "level of uncertainty data " describes the magnitude of the existence of reducible uncertainties in the data, the data used to estimate the uncertainties in the input parameters. For practical purposes it was enough to define two levels of uncertainty data, the basic level and the mixed level:

- Basic level, i.e. the data of the uncertainties in the input parameters contain only irreducible uncertainties. For example, for the uncertainty in the leakage of windows, we may have the uncertainty data for windows with definitive design parameters, such as type and material of windows.

- Mixed level, i.e. the data of the uncertainties in the input parameters is a combination or mixture of reducible uncertainties and irreducible uncertainties. For example, the uncertainty data is only available for a set of windows, which includes windows with different design parameters, such as windows having various types and made of different materials. A worked out example is given in Yang (Yang, 2012).

4 APPROACH TO CARRY OUT THE UNCERTAINTY QUANTIFICATION ANALYSIS

Different approaches should be used to obtain the data of the uncertainties in the input parameters for the two different uncertainty levels, i.e. the accurate approach and the prototype approach as described below.

4.1 Accurate approach

When we are carrying out an assessment where a small amount of reducible uncertainties exist in the ventilation system(s) to be assessed, as in, for example, the design level assessment, then we can use the accurate approach to prepare the uncertainty data. The basic idea for this accurate approach is that the uncertainty data used for the uncertainty quantification analysis should be the **basic level uncertainty data**.

The steps of the **accurate approach** are described below:

- step 1: Reduce the reducible uncertainty by dividing the ventilation systems under assessment into sub-sets of systems, and each set has definitive design parameters, or determining the possible definitive design combinations of the design parameters, i.e. the definitive designs.
- step 2: Estimate the basic level uncertainty data, i.e. the irreducible uncertainties in the input parameters, for each definitive design. Then, we will obtain one calculation uncertainty datasheet consisting of the irreducible uncertainties for each definitive design.
- step 3: Carry out the uncertainty quantification analysis using each calculation datasheet. For more information see (Yang, 2012) and (Yang et al. 2012).

This approach is considered to be accurate because it only estimates the irreducible uncertainties, but might only be suitable for the situation that the number of reducible uncertainties is small. If the assessment project includes a large number of reducible uncertainties, for example the global level assessment, the accurate approach may lead to a cumbersome process or is even not applicable. Thus, we developed another approach, the prototype approach, which is introduced below.

4.2 Prototype approach

When the assessment is carried out on a large set of ventilation systems, for example the global level assessment, the accurate approach introduced in sub-section 4.1 is not suitable to be used, and the prototype approach should be used.
The basic idea of the prototype approach is that the mixed level uncertainty data should be used together with the prototype ventilation systems. The detailed steps for the **prototype approach** are introduced below:

- step 1: Divide the set of ventilation systems to be assessed into sub-sets, each sub-set of the ventilation systems belongs to one prototype of the ventilation systems. A prototype of the ventilation system has a certain type of ventilation system and building floor plan. The prototypes should be developed from the whole set of ventilation systems to be assessed, and should be representative.
- step 2: Estimate the mixed level uncertainties for the whole set of ventilation systems to be assessed, or estimate the mixed level uncertainties for each sub-set of ventilation system within one prototype according to Yang (Yang, 2012). Then, these uncertainties can be used to form the calculation uncertainty datasheets, one calculation uncertainty datasheet for each prototype.
- step 3: The uncertainty quantification analysis can be carried out on every formulated calculation uncertainty datasheet in step 2.

4.3 Selection of an approach for different cases of assessments

As introduced above, different approaches, i.e. the accurate approach or the prototype approach should be used for assessments with different magnitudes of reducible uncertainties.

As shown in table 2, for different assessment cases we therefore propose to use a different approach.

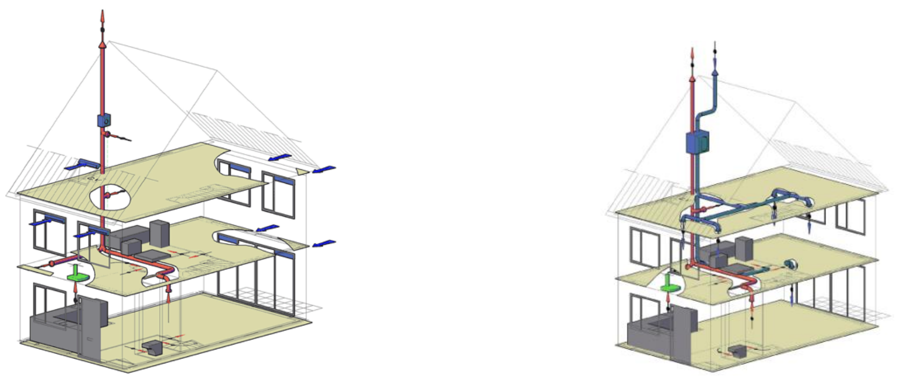
Table 2: Recommended assessment approach for each assessment case

	all four aspects: - ventilation components - building components - outdoor environment - type of occupants	system aspects: - ventilation components and/ or, - building components	boundary aspects: - outdoor environment and/ or, - type of occupants
A: global level	uncertain (A1): - prototype approach	uncertain (A2): - prototype approach	uncertain (A3): - prototype approach
B: project level	uncertain (B1): - prototype approach or, - accurate approach	uncertain (B2): - prototype approach or, - accurate approach	uncertain (B3): - prototype approach or, - accurate approach
C: design level	uncertain (C1): - accurate approach	uncertain (C2): - accurate approach	uncertain (C3) - accurate approach
	certain (C4): - accurate approach		

5 A DEMONSTRATION

In order to demonstrate the concepts and approaches introduced above, we chose to illustrate the prototype approach. Assuming an assessment was required to be carried out on the performance of ventilation systems in low-storey houses located in a certain area in Delft (NL). There are different types of houses with similar floor plan but different details. Considering the concepts and approaches introduced above, the following analysis was made:

- Two main types of ventilation systems are used in these houses, i.e. mechanical exhaust with natural supply system (MENSS) and balanced ventilation with heat recovery system (BVHRS). The assessment level is “project” and consists of two types of ventilation systems and is therefore a B2 case, see table 2. The prototype approach was chosen because of the large difference between the two ventilation systems. For the analysis, first the two prototypes were selected as shown in figure 1 a/b below. It was assumed that the systems were equally distributed over the dwellings.



1a: MENSS system prototype 1b: BVHRS system prototype

Figure 1: Prototype ventilation system, MENSS & BVHRS (Source: ISSO 92 & 62)

- Then, in each prototype system only two uncertain design parameters were considered, i.e. building orientation and fan curve. It was assumed that the building can face any orientation in order to explore the effect of orientation on ventilation. The uncertainty in fan curve was used to see the influence of using different types of fans on the ventilation.
- After identification of the uncertainties in design parameters, the next thing is to estimate the uncertainties in the input parameters for each prototype system. The estimated uncertainties for this example of these two systems are listed in table 3 below. The designs of the ventilation components are mostly assumed to be definitive. The values of the design parameters in this example can be seen in table 3 below.

Table 3: Uncertainties used in the example

parameters	Type of PDF Variation range	unit	estimation basis
window leakage	normal (0.086, 0.41)	$dm^3/(s.m.pa^{-n})$	AIVC GUIDE 05
leakage of the joint between window/ door frame and wall	normal (0.00033, 0.012)	$dm^3/(s.m.pa^{-n})$	
internal door leakage	normal (1.1, 2)	$dm^3/(s.m.pa^{-n})$	
external door leakage	normal (0.082, 0.84)	$dm^3/(s.m.pa^{-n})$	
facade leakage	normal (0.016, 0.021)	$dm^3/(s.m^2.pa^{-n})$	
leakage through the joint wall/ ceiling	normal (0.005, 0.11)	$dm^3/(s.m.pa^{-n})$	
roof leakage	normal (0.6, 1.1)	$dm^3/(s.m^2.pa^{-n})$	
duct leakage	normal	$dm^3/(s.m^2.pa^{0.65})$	LUKA classes, & assumption
Positions of exhaust/ supply grilles	Normal (-10%, 10%)	/	Assumption
Heat recovery efficiency	Normal (70%, 90%)	/	Product information literature
Internal leakage	Normal (0, 0.0001)	$kg/(s.pa^{0.65})$	Some measurement data and inquiry
Duct pressure loss coefficient	Normal (-20%, 20%)	/	Assumption
Terrain roughness (4 directions)	Uniform (0.25, 0.4)	/	Based on the definitions in the manual of TRNFLOW
wind pressure coefficients	Uniform (-10%, 10%)	/	Cp-generator & empirical accuracy of Cp-generator
Local temperature premium	Uniform (0,1)	^oC	Literature and assumptions.
Indoor temperature set-point	Normal (12, 21) daytime (14, 21) evening (10, 19) night	^oC	Estimation from survey data from VROM

(Note: table 3 includes the uncertainties both for MENSS and BVHRS, while some uncertainties only account for BVHRS, such as heat recovery efficiency and position of supply grilles.)

- After identification of the uncertainties, the calculations were made, i.e. 140 calculations for the uncertainty propagation analysis and 116 calculations for the sensitivity analysis for each prototype system were executed. The important results are summarized below:

- Both systems had steady exhaust air flows since the variations were less than 10% because they are both provided mechanically, for example see figure 2 and 3. However, the pressure loss coefficient contributed to most variations in the mechanical air flow rates.

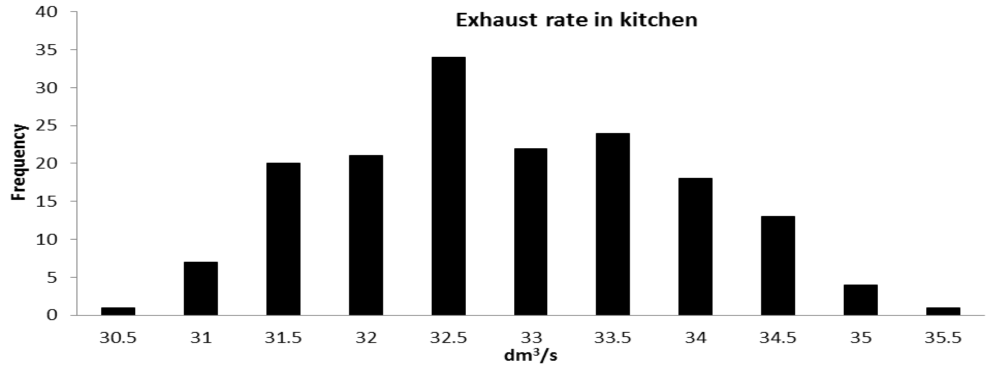


Figure 2: Annual averaged hourly exhaust air flow rate in kitchen in MENSS

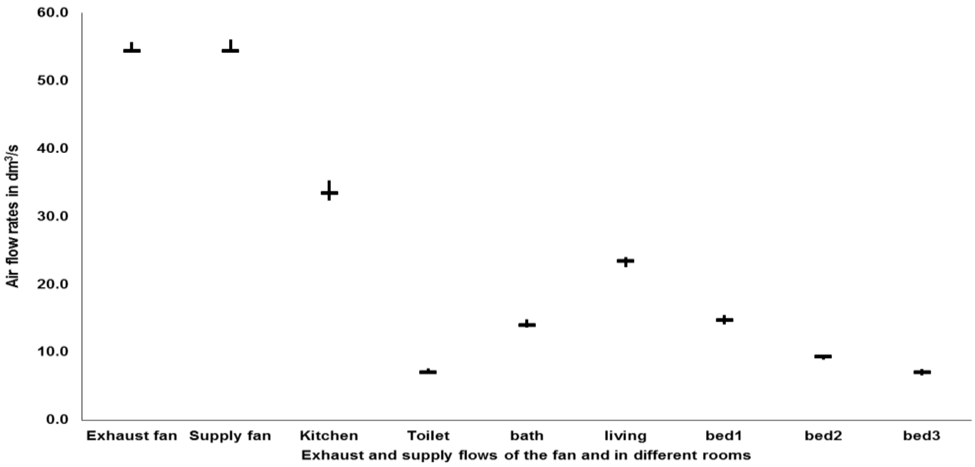


Figure 3: Annual averaged hourly exhaust/ supply air flow rates in BVHRS

- MENSS had very variable supply air flow rates as shown in figure 4 (as an example a bedroom is shown, see Yang (Yang, 2012) for more rooms), while BVHRS had quite steady supply air flow rates as shown in figure 3. The variations in the supply air flows were mostly caused by the uncertainties in the parameters “indoor temperature set point” and “building orientation”.

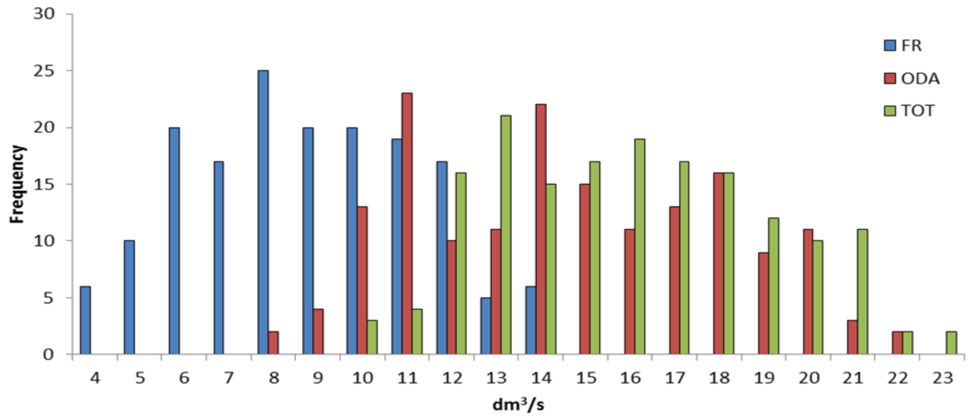


Figure 4: Annual averaged hourly supply air flow rates in bedroom in MENSS system
(Note: FR accounts only fresh air from air inlets; ODA accounts FR plus inside overflow from other rooms; TOT accounts for ODA plus infiltrations)

- After the analysis of the prototype systems, the results can be combined and the overall performance of the ventilation system in this assessment can be evaluated.

6 DISCUSSION AND CONCLUSION

The main aim of this paper is to introduce concepts, i.e. level of assessment, reducible and irreducible uncertainty, and level of uncertainty data. Two approaches are given to deal with the uncertainties in an assessment of ventilation system based on the introduced concepts. A simple demonstration is given to illustrate the described concepts and to show how the approach works.

One way to deal with assessment in complex situations with significant uncertainties is to decompose the case into sub-cases where each sub-case includes fewer uncertainties and can be estimated more accurately. This is the main idea described in this paper. The given concepts and approaches are considered to be useful tools for dealing with different kinds of assessments. Although the focusing point is on ventilation systems, the concepts about uncertainties can be applied to other fields as well.

However, the attempt to quantify the uncertainties in an assessment of domestic ventilation systems led to more questions. First, the boundary between the reducible and irreducible uncertainty actually depends on the specification of the components and the available data. The irreducible level must be used when the components cannot be specified into more sub-categories or there is no more data for such sub-categories. So the boundary between a reducible uncertainty and an irreducible uncertainty depends on the user of the concepts. Furthermore, the prototype approach is demonstrated in this paper with two arbitrarily chosen prototypes. The influence of the choice of the prototypes merits a future investigation too.

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