

A method for evaluating the problem complex of choosing the ventilation system for a new building

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SUMMARY

The application of a ventilation system in a new building is a multidimensional complex problem that involves both quantifiable and non-quantifiable data e.g. energy consumption, indoor environment, building integration and architectural expression. This paper presents a structured method for evaluating the performance of a ventilation system in the design process by treating quantifiable and non-quantifiable datasets together. The method is based on general morphological analysis and applies cross-consistency assessment to reduce the problem complex, thus treating the multi-dimensionality, the uncertainty and the subjectivity that arise in the design process on a sound methodological and scientific basis. Using a distance analysis of the shared values, the solution scenarios may be plotted relative to each other, which provides the designer with an illustrated 'space of solutions'. Herein the designer may view multiple ventilation solutions and navigate between them, evaluate the differences and choose a suitable ventilation system in terms of energy consumption, indoor environment and architectural quality.

INTRODUCTION

Analysing problem complexes like choosing the ventilation system for a new building presents the engineer and the architect with a number of methodological difficulties. The issue involves both quantifiable and non-quantifiable variables that are intercorrelated and due to the early stage in the design phase information is incomplete, missing or undetermined.

In this contribution we use morphological analysis to decompose and structure the problem complex into both objective (technical) and subjective (architecture) variables while treating incomplete information in a structured manner. One of the advantages of morphological analysis is that such combinations are valid. General morphological analysis has mainly been used for socio-technical problems [1] but also in a building related context e.g. to improve the comfort of various ventilation concepts [2].

Here we couple morphological analysis with cross-consistency assessment and a distance analysis to establish the feasible 'space of solutions' for different ventilation concepts within different building envelopes. This process is time-consuming but we have automated it by implementing it in a simplified yet fully dynamic building simulation program BuildingCalc [3] programmed in Matlab [4].

In the Methods section we describe the requirements and general theory for the method while illustrating it with a limited example. The results section contains the results and the xx at last we discuss the consequences that may be derived from the method and results.

METHODS

The methods section contains a chronological description of the methodological approach: establishing the building requirements, generating the morphological box, performing the cross-consistency analysis and the evaluation criteria and tools. Xx example

Requirements

The requirements for the ventilation system are specified in prEN15251 [6] and we use these to establish the initial design criteria for the ventilation system. In prEN15251 the ventilation and thermal comfort criteria are specified for different building types. The criteria are given as intervals in three categories I, II, and III for different building types. Thus we require initially the building owner to specify the use of the building, the desired category of indoor climate, the type of materials to establish the building pollution and the overall placement of the building on the premises to establish external shadows and prevailing wind conditions.

Table 1. The overall requirements specified by the building owner. Data is obtained from prEN15251 [6] and Danish Building Regulations [7].

Building type	Indoor climate category	Building pollution (no smoking)	Total vent. rate [l/s/m ²]	Temp. range [°C]	Energy frame [kWh/m ²]	External shadows	Wind conditions
Single office 18m ²	I	very low (0.5 l/s/m ²)	1.5	21.0-25.5	95.5 ¹	None	Good enough for nat. vent.

Morphological analysis

The background for general morphological analysis is to identify and investigate the total set of relationships or configurations contained in a problem complex.

The morphological analysis was developed by Fritz Zwicky and is described in [5]. It is used to structure *messes*, which are complex issues without well-defined form, into problems of unambiguous form and dimension.

In this contribution the morphological analysis is used to generate a problem matrix that enables us to decompose the problem complex into sets of functional subsystems. The decomposition is carried out hierarchically and continues until arrived at simple building functional components that can be described with a single variable. There are no formal requirements that the variables are of the same unit; technical, aesthetical and architectural elements, known or hypothesized, are treated together to create a space of solution for the designers. Hence the method is flexible xx the example which is used here does not encompass all ventilation variables or dimensions possible.

¹ At a heated floor area of 3000 m².

The decomposed problem is put into a ‘box’ which is depicted as a chart in Table 3. The dimensions and variables are listed in the left columns and the values are listed in rows. The combination of variables with arrays of values makes up the morphological box.

To start the morphological analysis we need to:

1. Identify the *aspects* of the problem complex. Aspects are also referred to as *dimensions* because they represent the sides in the n-dimensional morphological box. In Figure 1 comfort, energy and building characteristics, and aesthetics are chosen as dimensions.
2. Each dimension is governed by a set of variables. E.g. comfort is achieved through fresh air supply and the ability to cool or heat when necessary (Figure 1).
3. Each variable may attain a well-defined range of values or conditions. In practise the ranges are discretized on the basis of a user perception of low, medium and high values.² Thus uncertain or hypothesized values are represented on a backwards traceable methodological basis.

Table 3 illustrates the morphological chart. The imaginative values (high, medium, low) are exchanged with real numbers that *we* regard as representing high, medium and low values. The chart has been reduced for the purpose of illustration and to reduce computation time. Thus the parameters in Table 2 are fixed.

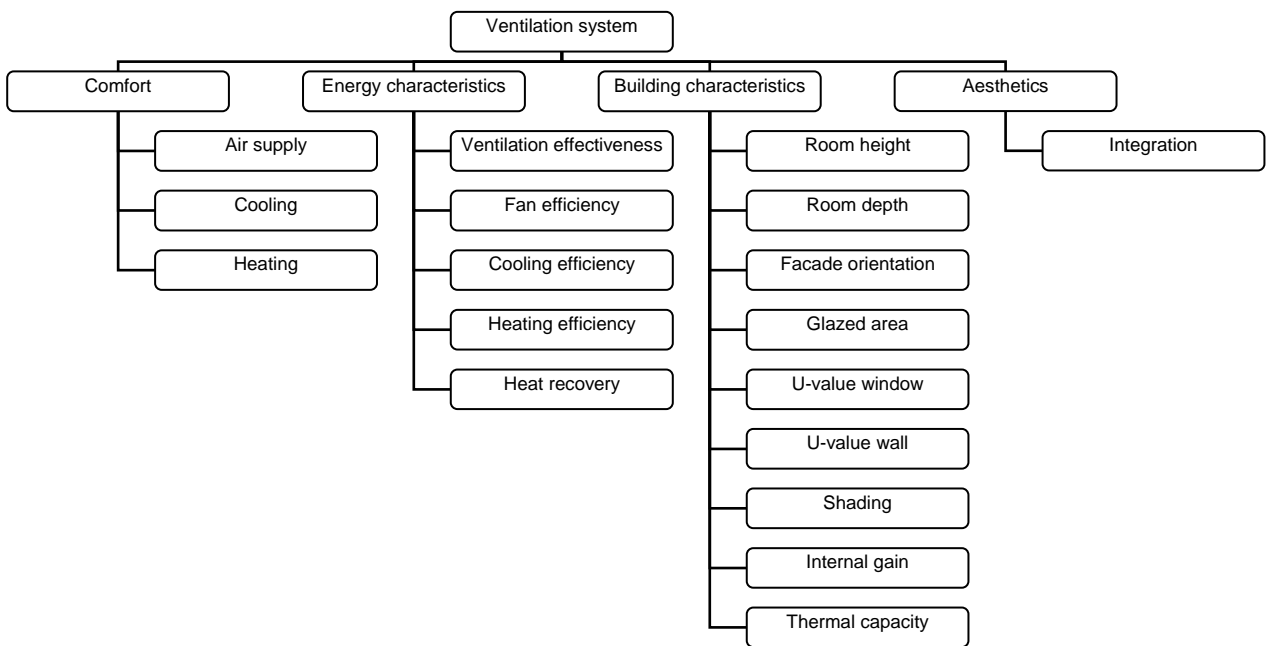


Figure 1. The problem complex decomposed into dimensions and variables.

Table 2. Fixed and excluded values from the morphological chart in Table 3.

Depth of room	Average U-value of window	Average U-value of wall	Façade length	Façade orientation	Min. shading factor
6 m	1.4 W/(m ² K)	0.15 W/(m ² K)	4 m	South	0.2

Four system/user profiles have been specified: working hours, outside working hours, heating season and outside heating season.

² The exact number of discrete values is user defined.

Table 3. Example of a morphological box for a ventilation system in a building. The greyed out areas represent the reduced problem which is used in CCA in Table 4.

Dimensions	Variables	Values			
Comfort systems	Ventilation 1 Supplied air* [l/s/m ²]	Natural calculated	Fan-assisted 1.5-3.0	CAV 3.0	VAV 1.5-7.5
	Ventilation 2 Supplied air* [l/s/m ²]	Natural calculated	Fan-assisted 1.5-3.0	CAV 3.0	VAV 1.5-7.5
	Cooling 1 Max cool. power [W]	Mech. increased vent. rate calculated	Night cooling calculated	Cooling unit 10	Chilled beams 30
	Cooling 2 Max cool. power [W]	Mech. increased vent. rate calculated	Night cooling calculated	Cooling unit 10	Chilled beams 30
	Heating 1 Max heat. power [W]	Radiator ∞	Heating coil 10	Heat pump 10	
	Heating 2 Max heat. power [W]	Radiator ∞	Heating coil 10	Heat pump 10	
Energy characteristics	Vent.effecness [-]	Low 0.7 (natural)	Medium 0.9 (mixing)	High 1.3 (displacemnt)	
	Fan efficiency SFP** [kJ/m ³]	Low 0 (no fan)	Medium 1 (extract only)	High 2	Very high 2.5
	Cooling efficiency COP [†] [-]	Low 1 (cooling w/ outdoor air)	Medium 3	High 4	
	Heat recovery [%]	Low 0 (no heat rec.)	Medium 65	High 85	
	Heating efficiency [-]	Medium 1 (waterbased)	High 3 (heat pump, COP)		
Building characteristics	Room height [m]	Low 2.5	Medium 3	High 3.5	
	Glazed area [%]	Low 25	Medium 40	High 60	Very high 80
	Internal gain [W/m ²]	Low 10	Medium 25	High 40	
	Thermal capacity [kJ/(m ² K)]	Light 144	Medium 288	Heavy 432	Very heavy 576
Aesthetics	Integration of vent. system	Visible	Somewhat visible	Invisible	

* 'Supplied air' is the required minimum by prEN15251 during occupancy. Some of the systems (CAV, VAV) may be able to supply additional air (for cooling purposes). The user defines the desired ventilation ranges of the systems.

** SFP: annual average specific fan power. A measure of the efficiency of the ventilation fans and the pressure loss in the system.

† COP: annual average coefficient of performance. A measure of the efficiency of the cooling system.

Examples of questions for assessing the CCA matrix: useraction related xx:

- Is it possible to have a building scenario where a cooling coil in the second cooling system coexists with a night cooling system in the first cooling system? Obviously this is possible. Hence no marking is used.
- Is it possible to have an efficient heat recovery of 85 % and a specific fan power of zero? This is illogical, so the pair is marked with an I.
- Is it possible to have a room height of 2.5 m together with a natural ventilation system? This is a possibility, but the literature states that natural ventilation performs better if the room height is 3 m xx. Hence an U is used because the user assesses that on a normative basis this particular combination is unwanted.

Evaluation criteria

The morphological approach generates a large number of configurations or scenarios as depicted on Figure 2. We evaluate the scenarios on the basis of total energy consumption, indoor climate (PPD-hours) and annual total cost. For electrical appliances a primary energy factor of 2.5 is used [7].

PPD-hours are calculated from the annual sum of hourly values of predicted percentage dissatisfied [8]. Local discomfort is not considered and relative humidity and air velocity is fixed to 50% and 0.15 m/s respectively. The ventilation rate is not considered as we assume that the minimum ventilation requirements are always met.

Total costs are based on the sum of the annualized constructing and yearly running costs of the ventilation system.

Distance analysis

One of the most important goals in visualising data is to provide the viewer with a sense of distance between the plotted points. While it is straight-forward to plot scenarios based on two criteria, e.g. energy consumption and PPD-hours, the designer is not provided with the overall picture. With a large number of dimensions (>3), it is very difficult to visualise distances unless the data can be reduced to 2 or 3 dimensions. Hence a dimension reduction is necessary. Metric multidimensional scaling (MDS) is a set of statistical methods that address this type of problem. The methods are available in a toolbox in Matlab and we use them to plot the selected scenarios relative to each other to obtain an instant sense of the distances between them. The interscenario distances are not Euclidean but the *configurational* or technical distances, or more precise the pairwise dissimilarities between the scenarios. I.e. a technical distance of 1 between two configurations indicates that they have been produced from the same set of values except for 1 value that has been replaced by its horizontal neighbour in the morphological box.

It is evident that a certain amount of distortion has to be tolerated when a multidimensional dataset is reduced to two or three dimensions. In typical MDS applications an investigation into the significance of the error is conducted via Kruskals Stress criterion ref xx (stress1) where values are excellent below 0.1 and unacceptable above 0.15. The stress1-value on Figure 4 is 0.12. If the criterion is exceeded the user must reduce the number of selected configurations or raise the number of depicted dimensions from 2 to 3.

RESULTS

In this section we show the results that may be obtained using the method. The initial requirements established by the fictive building owner are shown in Table 1. A total of 248,832 scenarios was simulated with BuildingCalc taking approximately 80 minutes on a laptop with a Pentium M processor running at 1.86 GHz and 1 GB of RAM.³

In Figure 2 all the configurations derived from Table 3 and Table 4 have been simulated and depicted with respect to energy consumption and PPD-hours. With the BuildingCalc tool it is possible to pick the most interesting configurations, typically with respect to low energy consumption and low PPD-hours. Figure 3 depicts the predominant value settings of the 30 selected configurations. With the predominant values as starting points it is possible to reformulate the morphological box and resimulate with refined values.

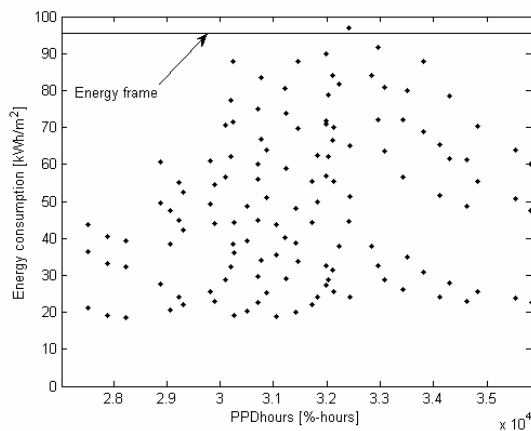


Figure 2. The distribution of ventilation configurations produced via the morphological box.

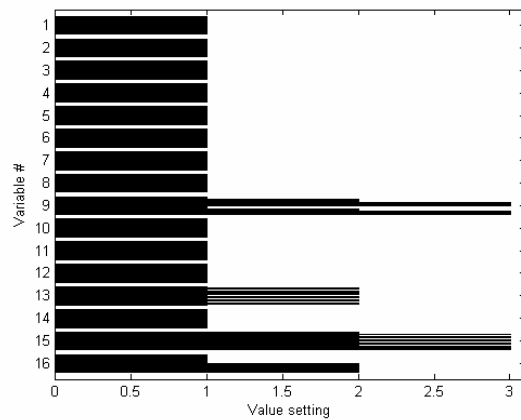


Figure 3. Predominant values for the 30 selected configurations. The variables are numbered consecutively as in Table 3.

Establishing a linear correlation between bubble size and total costs we use the MDS method to plot the selected scenarios relative to each other in Figure 4. We may navigate between them and explore their similarities simply by clicking on the points with the mouse.

³ Only a part quantity of the total number of configurations requires lengthy thermal simulation time.

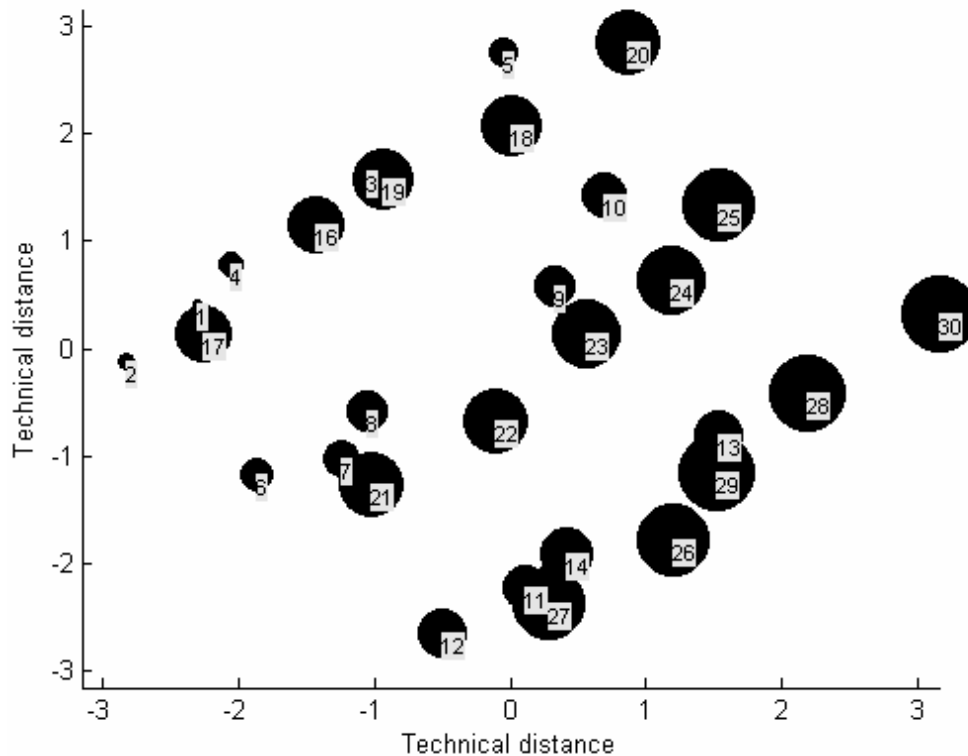


Figure 4. The relative technical distance between the 30 selected scenarios. Bubble Size xx

xxThe distances between the points are the distances expressed in terms of ‘technical distance’. Two points closely spaced represents two ventilation scenarios that are very similar to one another. The MDS method visualizes the morphological chart to the engineer and he is able to distinguish between multiple scenarios because their visual distance is a measure of their similarity. Thus

Figure 4 illustrates a space of solutions, where it becomes clear that scenario 3752 xx is better than 2030 if 3758 is not entirely suitable to the engineer or the architect.

DISCUSSION

The method described in this paper offers a deep insight into the problem complex of choosing a suitable ventilation system for a building. The morphological approach exempts the engineer from generating biased scenarios and by coupling the morphological analysis with cross-consistency assessment we ensure that the subsystems are unambiguously defined. The method is fully scaleable to the needs of the user and it allows for treating quantifiable and non-quantifiable datasets parallelly while remaining backwards-traceable. However the method also requires a certain amount of skills and practise to be able to setup the morphological box, cross-assess and iterate, but the procedure helps to keep out garbage input and to decompose the problem complex correctly.

The MDS method is limited to a certain number of configurations and dimensions, but it provides an excellent visualization and overview of the feasible configurations to discuss among engineers and architects in the design phase.

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