Multicriteria assessment of natural ventilation potential of a site

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ABSTRACT

A method is proposed to assess the natural ventilation potential by taking into account the most comprehensive set of factors involved in natural ventilation. These factors are either driving forces, such as wind pressure and stack effect, or constraints, like noise pollution and atmospheric pollution. The process considers these factors in an ordinal qualitative scale and gives its result in this same scale.

This bypasses the problem of the inaccuracy of some parameters, which can be very high, especially in urban environment and in the pre-design phase of a construction project. Actually, the method is particularly suitable for designers intending to take early-stage decisions.

1. INTRODUCTION

Factors involved in natural ventilation are *incommensurable*. This means that, if all considered, they cannot relate or be reduced to another single criterion. Moreover, these factors cannot in most of the cases be evaluated easily with a good accuracy. Both these reasons led to the choice of multicriteria analysis as a tool for evaluating the potential for natural ventilation. This approach will help to cope with the incommensurability and the uncertainty of the problem, by using *ordinal* scales for each criterion as well as for the final evaluation.

Problems of natural and hybrid ventilation are usually solved by means of airflow simulation tools. These tools are either computational fluid dynamics, zonal, nodal, or empirical models. They solve the equations of fluid dynamics or simplified equations to compute for instance the airflows in the building or parts of it. However, they do not take into account all factors involved in natural ventilation, like external noise, external pollution or safety compromising. Furthermore, they tend to propagate and to increase the uncertainty of the input parameters, which is for some parameters, like pressure coefficients, already high, especially in the early phases of a project. It has been proven (Fürbringer, 1994) that the higher the complexity of the simulation tool the higher this uncertainty increases.

2. CRITERIA INVOLVED IN NATURAL VENTILATION

2.1 Driving forces

The two driving forces of natural ventilation are wind pressure and stack effect. These forces induce a pressure difference on the building, which in turn generates airflows in it. The wind-induced pressure difference is given by:

$$\Delta p_w = \frac{1}{2} C_p \rho v^2 \tag{1}$$

with

Δp_w: difference between the static pressure on a given spot on the building envelope and the upstream reference static pressure (in an undisturbed zone),
C_p: pressure coefficient for a given spot on the building and a given wind direction,
ρ: air density,
v: upstream reference wind speed.

Pressure coefficients are determined either experimentally in a wind tunnel or numerically using computational fluid dynamics.

The other driving force of natural ventilation is stack pressure, or pressure due to buoyancy. It is induced by density differences between the indoor and outdoor air. The Bernoulli equation, combined with the ideal gas equation of state, leads to the stack pressure difference between two openings separated by a vertical distance h:

$$\Delta p_s = \rho_i \, g \, h \, \frac{T_i - T_e}{T_e} \qquad (2)$$

where ρ_i is the internal air density, g is the acceleration of gravity, T_i and T_e are the internal and external air temperature. In the absence of wind, when $T_i > T_e$, the air enters through the lower openings and goes out through the upper ones (upward flow). A downward flow takes place when $T_i < T_e$.

2.2 Constraints

The two constraints to natural ventilation retained here are noise and pollution. Others exist, such as compromising the safety of the building while leaving windows open, or the fact that the occupants do not interact in a proper way, but we just mention them.

Noise is a constraint to natural ventilation when the building is occupied. The definition of the acceptability of noise used in the current methodology is inspired by the Swiss federal regulation, which resorts to degrees of sensitivity:

- high: zones requiring an increased protection against noise, such as relaxation areas;
- medium: zones where no disturbing company is allowed, such as residential areas and areas restricted to public facilities;
- low: zones where disturbing companies are allowed, such as industrial, agricultural and craft areas.

In order to assess the outdoor air quality, the following pollutants are usually considered: nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), volatile organic components (VOC).

These pollutants each have long-term, short-term limiting values or both. For instance, the Swiss environment protection law (LPE) imposes for nitrogen dioxide a daily limiting value of $80 \, \mu g / m^3$, whereas the annual limiting value is $30 \, \mu g / m^3$.

3. METHOD

3.1 Assumptions of the method

The first assumption made in the current methodology is that the building will be built in a way that gets the most out of the potential for natural ventilation. The same goes in case of refurbishment.

In addition, it is supposed that the building occupants are aware of natural ventilation and open the windows or *ad hoc* openings accordingly.

The third assumption is that, given two city locations with different *local*[1] wind speeds, *wind-driven natural ventilation will be more effective at the location having the highest wind speed*, (provided that natural ventilation is assessed in the same type of building in both locations).

This assumption on wind will also be valid in the present method for the three last criteria, which are stack effect, noise and pollution (obviously in a reverse way for the last two, since they are constraints and not driving forces).

Finally, it is assumed that wind and buoyancy will never counteract each other. (It is always possible to configure opening in such a way.)

3.2 Justification of the resort to multicriteria analysis

Multicriteria analysis is a technique devoted to lighten a decision problem and to help solve it. This problem is made up of several possibly conflicting objectives, translated into criteria. The expected result of a multicriteria evaluation is an action or a group of actions to be taken (Schärlig, 1990a; Schärlig, 1990b). In our case, the actions are ‘to build at a given place’ and the decision to come to is ‘where to build’. This is why *action* and *location* have the same meaning in the following text.

A general property of multicriteria aggregation methods is their ‘monotonicity’,

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[1] *Local* wind speeds result from the influence of the building surroundings.

that is to say that if any of the criteria improves (respectively worsens), then the global evaluation improves (respectively worsens). In our case, if for example, wind blows stronger in a second situation than in a first one (without changing the other criteria), then the global evaluation of the natural ventilation potential will be better in the second situation. Similarly, if a location is noisier in a second situation than in a first one, then the global evaluation of the natural ventilation potential will be better in the first situation. This ‘monotonicity’ is fully coherent with the third aforementioned assumption. This is the first justification for using multicriteria analysis.

As another reason, a qualitative multicriteria method is able to cope with the lack of information always encountered in the early stages of a building project.

3.3 Principles of the multicriteria analysis method Qualiflex

The principles of Qualiflex (Paelinck, 1976; Paelinck, 1978; Paelinck, 1979) are explained hereafter in a simplified way thanks to an example made up of three actions a_1, a_2, a_3 (three sites in our case) and three criteria c_1, c_2, c_3.

Let us assume that each action (each site in our case) is assigned a rank for each criterion and that each criterion is assigned a weight. Figures in italics in Table 1 represent the *ranking matrix* elements.

In this example, for the first criterion (whose weight is 5), a_1 is better placed than a_2 and a_3, which in turn are equally placed.

The next step consists in considering all of the possible action rankings R_i, for $i = 1,\dots, (3!)$.

R_1: a_1, a_2, a_3
R_2: a_2, a_1, a_3
R_3: a_3, a_1, a_2
R_4: a_3, a_2, a_1
R_5: a_2, a_3, a_1
R_6: a_1, a_3, a_2

Table 1: Input table. The ranking matrix elements are represented by figures in italics.

weight	c_1	c_2	c_3
	5	4	1
a_1	*1*	*2*	*3*
a_2	*2*	*1*	*3*
a_3	*2*	*3*	*2*

Table 2: Matrix of concordance indices.

weight	c_1	c_2	c_3
	5	4	1
R_1	2	1	–2
R_2	0	3	–2
R_3	–2	1	0
R_4	–2	–1	2
R_5	0	–3	2
R_6	2	–1	0

For each ranking R_i and for each criterion, the concordance with the ranking matrix must be checked by comparing every couple of actions. Each time the relative position is the same (respectively different) in the ranking matrix of the problem data and in the ranking R_i, a so-called concordance index is incremented (respectively decremented) by one.

In our example, let us consider ranking R_4 and criterion c_2. For each couple of actions:

- R_4 causes a_2 to be better placed than a_1. So does the matrix for criterion c_2. The concordance index is thus incremented.
- R_4 causes a_3 to be better placed than a_1. The matrix causes a_1 to be better placed than a_3 for criterion c_2. The concordance index is thus decremented.
- R_4 causes a_3 to be better placed than a_2. The matrix causes a_2 to be better placed than a_3 for criterion c_2. The concordance index is thus decremented.

Therefore, the value of the concordance index for R_4 and c_2 is $1–1–1 = –1$[2]. By repeating this operation for every couple (R_i, c_j), the concordance indices take the values in Table 2.

A so-called global concordance index is then calculated for every ranking by adding the concordance indices of the ranking beforehand multiplied by the corresponding weight. For example, the global concordance index of R_4 is: $–2 \times 5 – 1 \times 4 + 2 \times 1 = –12$. And for the remaining rankings as shown in Table 3.

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[2] A minor modification has been brought to this procedure: the concordance index of a given ranking is decremented also if the ranking matrix gives two actions equally placed for a criterion and if the actions differ of more than one position in this given ranking.

Table 3: Global concordance indices.

	global concordance index
R_1	12
R_2	10
R_3	–6
R_4	–12
R_5	–10
R_6	6

If these indices are considered, it comes out that the first ranking R_1 accords best with the data of the problem. So the ranking R_1 causing a_1 to be better placed than a_2, in turn better placed than a_3 will be chosen.

4. RESULTS

The method presented above has been implemented in a piece of software whose objective, amongst others[3], is to assess the potential of natural ventilation.

Once the ranking matrix is filled (see below), the program supplies a sites’ ranking drawn up with previously established weights. Default sites are provided with the software.

4.1 Filling out the ranking matrix

Several frames (questionnaires) appear during the program execution in order to collect information from the user:

Undisturbed wind

The user is asked to enter the location of interest. The coordinates are then used to determine the undisturbed wind speed and direction through time thanks to data provided by the Swiss national weather service (Swiss Federal Office of Meteorology and Climatology, MeteoSwiss). Weather data have been indeed collected from the results of a complex atmospheric simulation tool, a prediction model solving the primitive hydro-thermodynamical equations describing compressible non-hydrostatic flow in a moist atmosphere, by using the finite difference method. These data provide the wind speed and direction at an altitude of 10 metres (32,8 feet) above the ground for 125’125 points across Europe with a spatial resolution of 7 km (4,35 miles) and a temporal resolution of four times per day (Steppeler et al., 2002).

Local wind

The user is asked to enter the environment of the place of interest and, if any, the characteristics of the canyon located there. These inputs, along with the undisturbed wind features, are used to assess the local wind speed and direction.

Stack effect

Outdoor temperatures are retrieved in MeteoSwiss’ data thanks to the location entered by the user. The free running temperature (internal temperature of the building where no heating, cooling or ventilation is used) is calculated using a thermal simulation program, that takes into account the thermal mass of the building, the solar gains and the internal gains. The internal building temperature is calculated by considering simultaneously comfort zones and respectively heating, cooling and ventilation. The stack effect can then be calculated using equation 1, along with this calculated internal temperature.

Noise levels

The user is asked to enter qualitative daytime and night-time noise levels in accordance with the degree of sensitivity (see section “2.2 Constraints”). Quantitative levels coming from measurements can be put by the user and then translated qualitatively.

Pollution levels

The user is finally asked to enter qualitative pollution levels. Pollution levels can be selected only qualitatively. The reason for this is that, quantitative pollution levels would require from the user a too large amount of measurements. Moreover, long-term *and* short-term limiting values exist for the pollutants of interest: nitrogen dioxide, sulphur dioxide, carbon monoxide, ozone and volatile organic components amongst other pollutants. Finally, the transport and transformation of pollutants is

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[3] The piece of software also provides (1) the degree-hours for heating, (2) for cooling, (3) the degree-hours of cooling saved by ventilation, (4) the fraction of time when passive cooling is possible during daytime, (5) the same fraction during nighttime and (6) airflow rates in a simple case.

Table 4: Ranking matrix.

	wind	*stack*	*pollution*	*noise*
weight	5	5	5	5
La Rochelle	*1*	*3*	*2*	*1*
Brussels	*2*	*1*	*2*	*3*
London	*3*	*2*	*1*	*3*
Porto	*4*	*4*	*2*	*2*

Table 5: Rating of the base sites.

	rating
La Rochelle	very high NVP
Brussels	high NVP
London	medium NVP
Porto	poor NVP

complex (Clappier et al., 2000). However, it can be conceived to use pollution maps. These are not available at a European scale yet.

All this collected information is used to calculate the levels of the four criteria, averaged over a two-year period. These levels are then inputted in the ranking matrix. (Allard and Ghiaus, 2005).

4.2 Example of results

Let us consider an example, where the sites of Table 4 have been previously put in the database. Table 4 follows the same notation convention as in Table 1. Every criterion has a weight[4] of 5.

Additionally, ratings have been given to each of the sites as shown in Table 5.

Now, let us suppose we intend to assess a site. In this example, a new site, namely Lausanne, is proposed for which the user fills out the software’s questionnaires. According to the user’s entries, the multicriteria analysis method ranks it in third position (Table 6).

Table 6: Ranking matrix.

	wind	*stack*	*pollution*	*noise*
weight	5	5	5	5
La Rochelle	*1*	*3*	*2*	*1*
Brussels	*3*	*1*	*2*	*3*
Lausanne	*4*	*2*	*1*	*3*
London	*2*	*4*	*2*	*3*
Porto	*5*	*5*	*2*	*2*

Rather than assigning a mark to the new site, the user can state that it is better than London (that has been rated by the expert as medium) and not as good as Brussels (that has been rated by the expert as high) from the natural ventilation potential point of view.

5. CONCLUSION

A semi-qualitative multicriteria analysis method has been implemented in a tool whose objective is the assessment of the natural ventilation potential of an urban site. This tool is meant for designers at the very early stages of a project of construction or of refurbishment. It takes into account driving forces and constraints of natural ventilation, in order to state whether or not a given site is appropriate for natural ventilation (and passive cooling).

It should be reminded at this point that the assessed natural ventilation potential is the potential of the *site*. Once a site with a good potential is found, the designer’s part is to construct a building or to refurbish an existing one in a way that makes the most out of this potential. In other words, both an appropriate site and an appropriate building are necessary conditions for natural ventilation to be applied.

This is a reason why this methodology is hard to validate: a proper validation would imply that buildings erected on the assessed site do take advantage at the best of the potential of those sites, which is rarely the case in existing constructions.

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[4] For editing reasons, the procedure used for finding weight can’t be made explicit here.

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