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Development of a Natural Soil Depressurization System Sizing Tool

Marc Abadie[1], Zaid Romani[1], Michel Burlot[1], Jérôme Nicolle[2], Pierre Peigné[3], Lionel Druette[3], Bernard Collignan[4], Francis Allard[1]

[1] LaSIE UMR CNRS 7356, La Rochelle Université, 23 avenue Albert Einstein, 17000 La Rochelle, France. [2] TIPEE platform, 8 Rue Isabelle Autissier, 17140 Lagord, France. [3] CERIC, CS 500 16, 79270 Saint-Symphorien, France. [4] CSTB Environment-Health Division, 24 Rue Joseph Fourier, 38000 Grenoble, France.

Corresponding author: marc.abadie@univ-lr.fr

Abstract. This paper presents a summary of the main developments and results achieved in the frame-work of the French research project called EVAL-SDS. This project aims to analyse the performance of Natural, i.e. without use of fan for extraction, Soil Depressurization Systems (NSDS) to protect the built indoor environment from soil gaseous pollutant (Radon, Volatile Organic Compounds…). In this paper, the aeraulic performance of NSDS is studied i.e. its capacity to extract air from the ground to protect building's occupants. To this end, we first performed measurements of airflow rates extracted by a NSDS integrated in a test-house during one year. Those data include various weather conditions (stack effect, wind) for several key parameters (wind extractor type, slab air permeability and basement pressure). Then, a dedicated calculation tool has been developed and validated against the experimental results. This numerical model has been used to evaluate the NSDS performance in France for different building heights and ventilation systems. The results show that NSDS succeed in creating a negative pressure under the building slab most of the time and that the extracted airflow rates can be enhanced by better design of wind extractor, association with mechanical insufflating ventilation system and thermal transfer from the building during the heating season.

1. Introduction

The entry and accumulation of gaseous pollutants from the ground to indoor environments can contribute to significant degradation of air quality and lead to health risks for occupants. In France, the national methodology for the management of polluted soils provides, if necessary, the implementation of constructive measures. In fact, after treatment of polluted soils, residual pollution could remain, which can have a negative impact on indoor air quality. The protective action on the building acts as complementarity action to manage the situation and to minimize the risk.

To date, the Soil Depressurization Systems (SDS) are recognized as effective preventive solutions. It is often recommended to implement such a system and to analyse whether natural (mentioned as NSDS hereafter) running is sufficient to reduce indoor concentrations or whether a mechanical system needs to be used instead. NSDS have low cost of operation and require low maintenance. However, the performance of such systems is difficult to assess as it depends on several parameters:

- Building characteristics: height, surface area, structure of the interface between the building and the ground (crawl space, supported or floating slab) and properties (air permeability);

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- NSDS geometry: height, diameter, structure of the interface between the NSDS and the ground (sump, drain);
- Soil properties: air permeability and pollutant diffusivity;
- Pollutant source: geometry (point/volumetric/plane source), location (under the building, dislocated).
- Meteorological conditions: air temperature and wind velocity;

Results from literature are sparse regarding NSDS performance. Angell [1] evaluated from measurements in real houses that NSDS can produce about a 50% indoor radon reduction and concluded that further research is needed to clarify the efficiency of passive strategies in new construction. Abdelouhab et al. [2] also concluded that the ability and the efficiency of the passive SDS are not properly characterized in the literature and need to be tested. The authors conducted a one-year follow up of a NSDS in an experimental dwelling on CSTB site (France). They showed that the system works particularly well during winter because of the temperature gradient between the building and outdoor. They also tested two types of extractors used to enhanced the wind-induced overpressure at the NSDS duct exit and showed a 50% impact on the extracted airflow rate. However, those results are limited to the characteristics of tested house and NSDS. In 2019, Hodgson and Pudner [3] compiled data from on-site radon measurements of buildings equipped with NSDS in England. They concluded that: NSDS reduces radon levels by a factor of around 1.6 when sealing floors and introducing permanent ventilation into the home have a reduction factor of around 1.3; rotating cowls on stack ducts increase effectiveness (from 1.6 to 2.1) and that passive systems are generally not as effective as fan powered systems but could be used as a viable alternative. In 2021, Zhou et al. [4] showed the potential of well-designed NSDS systems to reduce radon exposure in 21 new and retrofitted Canadian homes, reducing indoor radon concentration below 200 Bq/m^3 (the Canadian guideline value). They also observed the degradation of NSDS performance in homes having either a Heat Recovery Ventilation system (with frost formation reducing the ventilation air change rate of the building), a ground floor bathroom (reducing the ground-building interface airtightness and enhancing the stack effect within the building so more gas enters the building), or no stack insulation (limiting the NSDS stack effect).

The goal of the present study is to extend the previous analysis by introducing variation among the parameters. In a first part, we conducted experiments on a test house where three parameters can be modified: the type of extractor (as in [2]), the air permeability between the building and the ground and the building pressure to mimic different ventilation strategies. In a second part, we developed a simple model to allow additional parametric studies regarding the height and diameter of the NSDS duct and meteorological conditions. NSDS performance for the French territory was then numerically evaluated and is presented in the last part.

2. Experimental set-up and protocol

2.1. Description of the experimental test house

The Eureka test-house is intended for studies in real or partially-controlled situations. It is located at the TIPEE platform of the ATLANTECH low-carbon site in periphery of La Rochelle (Figure 1). The test-house is made up of 2 living floors with 8 rooms and 1 basement (100 m^2 floor area), the constructive materials have with very low pollutant emission, both the envelope airtightness and the mechanical/natural ventilation systems can be modulated (for full description, see [5]).

Figure 1. Location and picture of the Eureka test-house.

Figure 2 presents a schematic view of the studied NSDS along with pictures of its main parameters: static extractor, duct, sump, main slab and basement pressure control system. To avoid uncontrolled leaks, the basement slab periphery has been sealed. Additional calibrated cracks (2 mm in diameter) have been added to modify the slab resistance to airflow. A mechanical system (control fan) is dedicated to the control of the basement pressure (positive or negative) to represent ventilation systems commonly found in buildings.

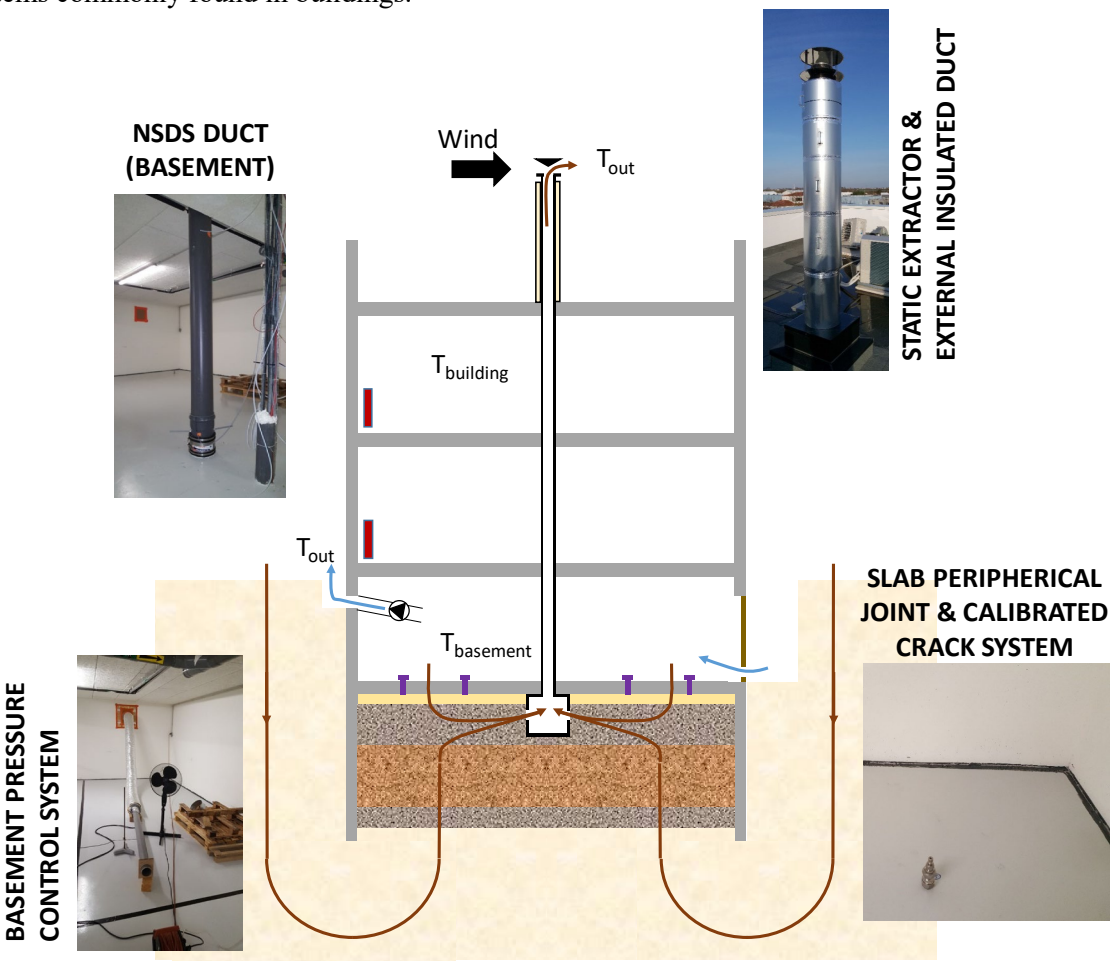

Figure 2. Schematic view of the studied NSDS.

2.2. Performance of the static extractor

Figure 3. Static extractors tested in this study.

A first study consisted in improving the performance of the static extractor to produce high wind pressure coefficient and low-pressure loss. The pressure drop of a system operating naturally, i.e. without mechanical fan, must be minimized as the stack and wind forces are not important (with a mean around 10 Pa for low-rise buildings with peaks of 50 Pa with strong wind). In the case of a NSDS, the airflow rate of extracted air (and therefore pollutant) is directly related to the linear pressure drop of the duct (whose diameter must be large enough to make it negligible) and the static extractor. In particular, during periods with little or no wind, the pressure drop induced by the extractor is the element limiting the extracted flow. An experimental test protocol has been developed at CERIC laboratory to quantify the pressure drop coefficient of existing terminals (classical) and to test new design of extractor (optimized). Figure 3 presents the tested static extractors. The optimized design is based on the last extractor shown in this figure (CAOI TZ 200) but is not presented here because of confidentiality.

2.3. Experimental protocol

The main experiments consisted in measuring the airflow rate in the NDSD for different configurations of static extractor, slab airtightness and basement pressure levels (Table 1). Each measurement campaign lasted 2 weeks with data acquisition every 10s (basement, sump, duct inlet and outlet temperatures, pressure differences between outdoor/basement/sump and airflow rate in the duct). A dedicated weather station was located on the roof of the test-house to record wind velocity and orientation and outdoor air temperature.

Table 1. Experimental configurations studied in Eurêka test-house.

#	Static extractor	Slab airtightness	Basement ventilation
1	Optimized (cat. B*)	Airtight	Natural
2	Optimized (cat. B*)	20 mm × 8	Natural
3	Classical (cat. A*)	20 mm × 8	Natural
4	Optimized (cat. B*)	20 mm × 8	Mechanical – Exhaust (-)
5	Optimized (cat. B*)	20 mm × 8	Mechanical – Insufflation (+)

* Class identification by NF EN 13141-5 (février 2005)

3. Numerical model

A pressure network model (Figure 4) calculates the extracted airflow from the NSDS based on required inputs (wind velocity, outdoor and building/basement/sump temperatures) and parameters (R_1 and R_2 resistances have been measured by on-site sump pressurization tests, R_3 is calculated according to pressure losses in the duct parts and static extractor) considering the balance between the pressure loss and the combined effect of stack and wind:

$$\Delta p_{loss} = \left(\rho_{out} - \rho_{sump}\right) \times g \times H + CP \times \rho_{out} \times \frac{V^2}{2} \quad (1)$$

Where Δp_{loss} is the total pressure (Pa), ρ_{out} and ρ_{sump} are respectively the air density at outdoor and sump temperature (kg.m^{-3}), g is the gravitational acceleration (m.s^{-2}), H is the height of the duct (m), CP is the pressure coefficient (-) and V is the wind velocity (m.s^{-1}).

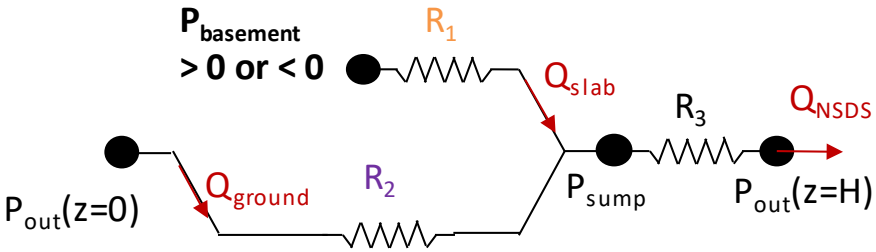

Figure 4. Pressure network model.

The model has been used to calculate the NSDS performance defined as the operating time of the NSDS in extraction (Q > 0 m^3/h) independently of the intensity of this airflow. It thus reflects the normal operation of the SDS, without inversion of the flow in the duct. The parameters are: geographical locations (53 cities in metropolitan France), duct diameter (from 5 to 30 cm by 1 cm step), duct height (10, 12, 16, 19, 22 m), slab airtightness (airtight but not perfect and with 8 holes of 20 mm in diameter), static extractor (category A and B) and pressure in the building (-10, 0 and +10 Pa).

4. Results and discussion

4.1. Extractor

Pressure loss coefficients for the static extractors presented in Figure 3 ranged from 5.0 (Venti 160) to 1.4 (CAOI TZ 20). The measurements of the depression factor have been performed according to NF EN 13141-5 (February 2005) in the CERIC wind tunnel. Figure 5 presents a picture of the wind tunnel along with the results for the optimized extractor (Category B). Note that all other tested extractors lied in the Category A or worse.

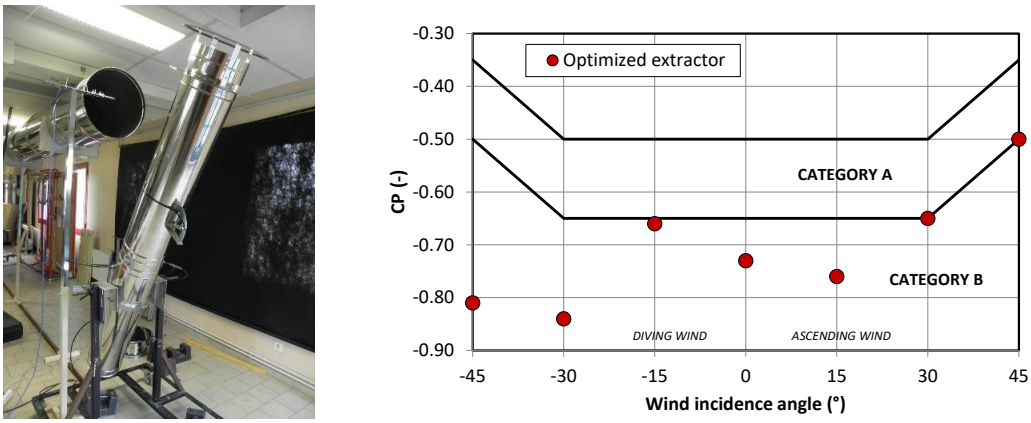

Figure 5. CERIC wind tunnel (left) and depression factor measurements for the optimized extractor (right).

4.2. In-situ measurements

Figure 6 presents the environmental conditions (outdoor-indoor temperature gradient and wind velocity) and airflow rate through the NSDS. A positive value of the airflow rate means that the NSDS works as it should as it extracts air from the sump. However, a negative value means that a reverse

airflow occurs, introducing outdoor air through the sump and potentially transporting ground pollutant to the house basement.

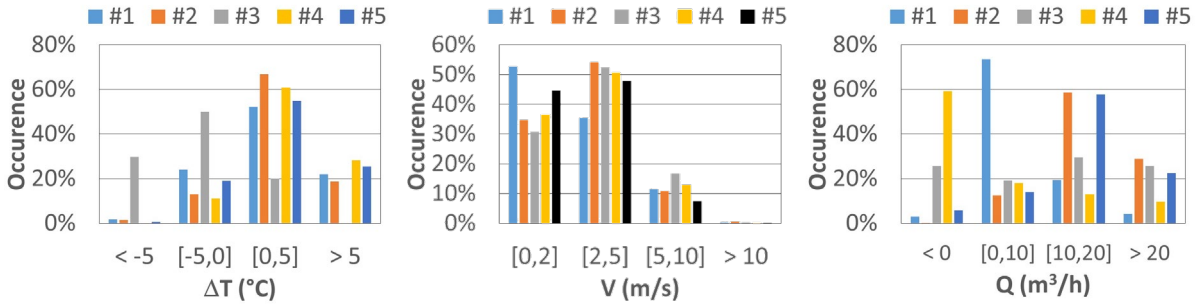

Figure 6. CERIC wind tunnel (left) and depression factor measurements for the optimized extractor (right).

The results of these in-situ tests allowed:

- To quantify the influence of the static extractor on the airflow rates extracted by the NSDS (comparison between #2 and #3): the improvement of the negative pressure induced by the optimization of the extractor (without significant modification of its pressure drop) allows to increase the extracted flow rates and to reduce the cases of airflow inversion in the duct.
- To determine the influence of the slab airtightness (comparison between #1 and #2): decreasing the slab airtightness allows an increase in the airflow rates extracted but does not modify the frequency of flow inversion. However, in the event of reverse flow, the entry of soil pollutants would be exacerbated, so it is important that the slab is as tight as possible when an SDS is installed.
- To evaluate the influence of the pressure prevailing in the basement (comparison between #4 and #5): an overpressure in the basement (representative of insufflating ventilation systems) allows to increase the airflow rates extracted and to limit inversions (Figure 7). Conversely, an exhaust ventilation system (putting the basement under negative pressure) increases the risks of inversion and induces lower extracted flows. The case of a natural ventilation system is an intermediate case to the two previous cases. Note that an inversion occurs when the negative pressure in the basement is higher than the sum of the stack and wind forces.

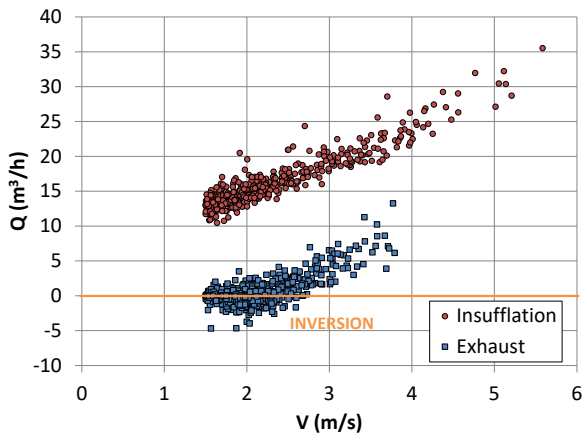

Figure 7. Comparison between configuration #4 and #5 with small stack effect (-2 < ΔT < 2°C).

4.3. Model validation and results

Figure 8 presents a comparison between experimental and numerical airflow rates obtained for configuration #3 (right) and the relative errors of the model for all configurations. On the whole, the relative error median value lies between 6% and 12%. Configuration #4 is a special case in which the airflow rates remained low and have oscillated positively and negatively around zero; this explains the relative error (division by a value close to zero) high.

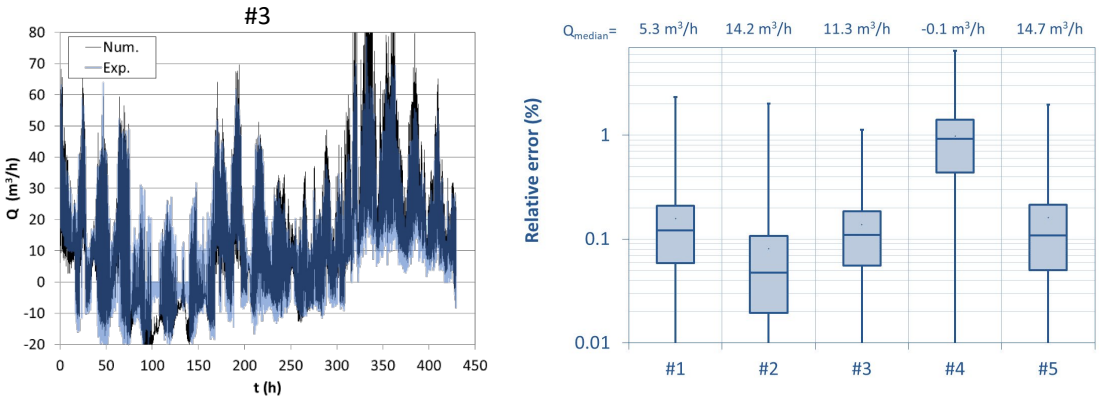

Figure 8. Comparison between experimental and numerical airflow rates for configuration #3 (right) and relative errors of the model for all configurations.

The use of this model to evaluate the NSDS performance under different climatic conditions representative of the French metropolitan territory has shown that for low-rise buildings (up to 5 storeys), a 20 cm diameter duct allows for optimal efficiency. It has also been shown that a NSDS in direct connection with a building in depression (e.g. a building ventilation by extraction) sees its performance deteriorate very quickly even with an airtight slab. Finally, the static extractor, when optimized, reduces flow reversal and thus improves the efficiency of NSDS and the safety in the use of this system (+15% increase of the extracted airflow rate compared with the use of classical one). All the results of the parametric study are available in [6].

As a first illustration, Figure 9 presents a map of the aeraulic efficiency of a NSDS in France for a classic configuration during the winter period. Because of local climatic conditions, the NSDS works normally during 100% of time (E = 1) mainly in the coastal, windy regions. In other regions, inversion of airflow can be present during 15% of time (E = 0.85) because of the lack of wind. Note that heat transfer from the heated building to the NSDS is not considering here. A supplement analysis showed that the efficiency increases 10% for a NSDS in direct contact with the heated building air and without thermal insulation.

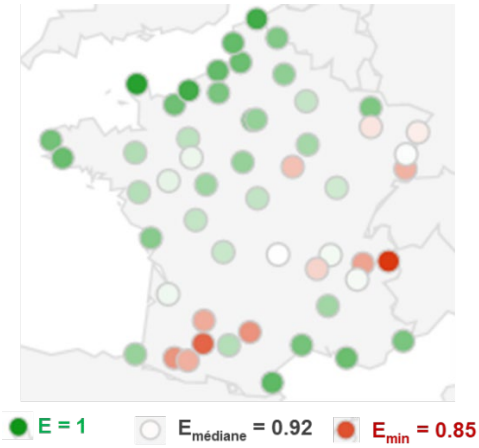

Figure 9. Map of minimal efficiency during winter (worst-case scenario with non-heated building) – 3 storey building, slab with 8 holes of 2 mm in diameter, category A static extractor, ΔP = 0 Pa.

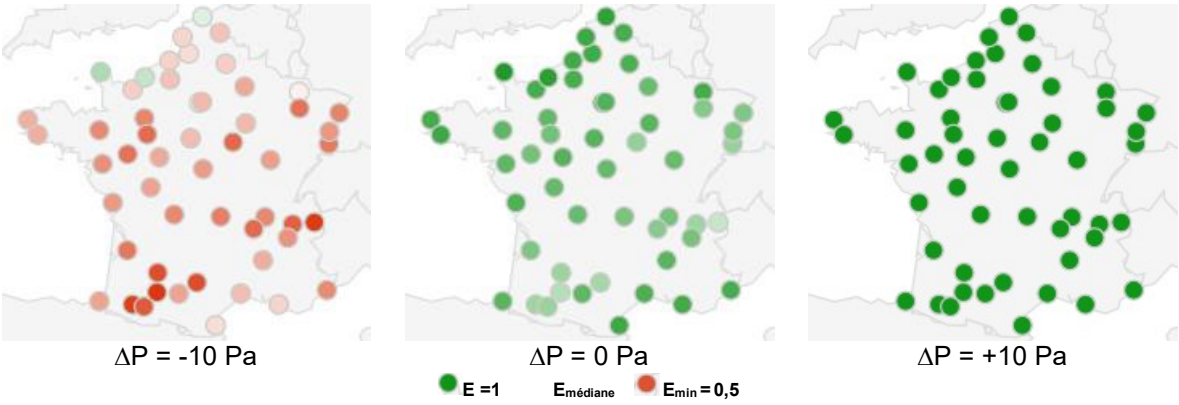

Figure 10. Map of minimal efficiency during winter – 5 storey building, airtight slab, category A static extractor.

Figure 10 illustrates the influence of the pressure in the building and confirms the trends observed during the measurements in the test-house. When the building is in negative pressure, the efficiency of the system is low with a value about 50% in most of the geographical locations. An increase to +10 Pa allows to reach a very high efficiency.

5. Conclusion

This study was limited to the evaluation of NSDS potential only in terms of extracted airflow rate from the ground below the building slab. The model developed in this project shows that NSDS performances are satisfactory for the metropolitan France climates. Perspectives are to account for pollutant diffusion that can have an impact when extracted airflow rate is low to improve our assessment of the NSDS performance.

Acknowledgments

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