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Method for Detecting Contaminant Transport through Leakages in a Condemned School

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ABSTRACT

Many schools in Sweden, have problems with the indoor air, affecting the wellbeing and health of both pupil and teachers. Contaminants in the air, such as mold spores, radon, odors, and VOC, cause problems and it can be difficult to find the contaminant source, in particular if it is within the building construction. The aim of this project is to investigate air leakage paths and pressure differences in a school building with IAQ problems and to analyze how these parameters are related to contaminant transport. An increased knowledge of how contaminants are transported will then form the base for an improved strategy for dealing with renovations of schools with IAQ issues. The main method of investigation in this initial part of the project is blower door measurements and leakage paths detection. A method to use CO_2 from dry ice as tracer gas for leakage detection is under development and tested in a condemned school building. Results presented in this paper show that it is possible to use this method to determine whether air leakages are coming from the crawlspace or from elsewhere.

KEYWORDS

air infiltration, tracer gas, air leakage detection, dry ice, contaminant transport

INTRODUCTION

There are several types of contaminants in indoor air, such as mold spores, radon, VOC (volatile organic compounds) and odors. The sources for these contaminants are both located in the rooms, in the building envelope and outdoor. The contaminants sometimes result from excessive moisture levels in the building envelope, which can cause increased emissions and mold growth. There are several studies showing possible contaminant sources that are connected to the building envelope and to moisture (for example Bornehag, 2005; Täubel, 2011, Cai G-H et al, 2011). In an investigation covering 220 schools and pre-schools, Hilling (1998) found that there are large deficiencies in maintenance, moisture safety, building airtightness and air treatment in Swedish schools.

The current work focus on the contaminant transport by air that moves through leakages in the thermal envelope. This requires a pressure difference (by wind, stack effect or ventilation) and a leakage path. Commonly, the pressure distribution is such that air infiltrates from a crawlspace, to the indoor air, bringing contaminants. The pressure at ceiling level often cause moist air to infiltrate attics, causing mold problems. However, in 10 % of the time, the pressure difference is adverse, such that mold contaminated attic air infiltrates into the indoor air (Sasic, 2007). The amount of air that passes through the building envelope and the origin of the air entering the building depends on the overall airtightness of the building and on the leakage path distribution (Sikander et al. 2009). The contaminant transport in the current work is investigated by numerical simulations, by tracer gas measurements (CO_2) and by measuring pressure distributions in a school building. Both field measurements and laboratory measurements have been performed to develop the measurement equipment and procedure.

METHODS

There are several ways to detect leakages in buildings, for example tracer gas, smoke, thermography (in combination with pressure differences), acoustic methods etc. However, in this work thermography in combination with CO_2 as a tracer gas is used. CO_2 is present in the atmosphere (at levels of approximately 400 ppm) and is produced in the building by occupants, from gas cylinders or from sublimation of dry ice.

CO_2 is chosen for several reasons, it does not easily react with other gases and it mixes well with air since its density is of similar order of magnitude as for air (slightly higher). CO_2 meters to use for measuring the CO_2 concentrations are easily found on the market and are often cheaper compared to other gas meters. CO_2 can be purchased as dry ice (CO_2-ice) which is used in the following experiments. Dry ice sublimates (in atmospheric pressure) at a temperature of -78.5 °C and has therefore to be handled with care in order to prevent frost damage.

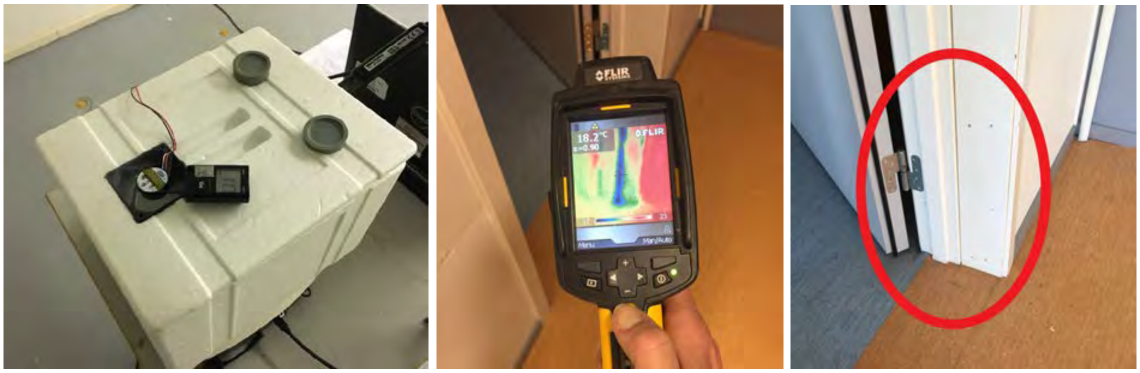

Figure 1. To the left: Icebox with dry ice, fan and heater. In the middle: Thermographic image of leakage at location L4. To the right: Image of leakage at location L4.

In this project, dry ice is used in an attempt to design a test methodology that is easy to use and inexpensive. The dry ice is placed in an insulated box, called icebox see Figure 1, with a fan to produce a steady air flow and on a scale to determine production rate. An electric heater is covered by the ice inside the box in order to increase the rate of sublimation. The advantages of dry ice compared to a gas bottle is that a higher production rate is achievable, a bottle can produce about 0.5 g/s (Konder 2008). The icebox used in this paper has a production rate of about 0.7 g/s, something which can be increased by using a higher power output on the heater. Initial tests are performed in laboratory to study production rates and distribution of CO_2 in a room. Laboratory tests of the ice box showed some stratification of the CO_2 in the room, which is why the icebox is complemented with two desktop fans, placed at some distance from the icebox, with the purpose of improve the mixing of air and CO_2 to prevent stratification. Other ways of dispersing CO_2 as dry ice were tested to estimate the sublimation rate, ease of use and repeatability. Spreading out 0.5 kg dry ice on the floor in a room with an air temperature of 20 °C had an average sublimation rate of 0.7 g/s. Interestingly, using a fan to blow air over the ice decreased the sublimation rate to 0.4 g/s. The reason to this is thought to be that more water condensates on the dry ice and works as thermal insulation. Submerging dry ice in boiling water had the highest average sublimation rate, 3.0 g/s. However, this method was the most inconvenient. If room tempered water was used, ice formed around the dry ice which stopped the sublimation. Field tests are performed in a school building in order to study real leakage paths. The principle of the field tests is to introduce CO_2 to one volume of the test building and measure change in CO_2 concentrations in adjacent volumes, in most cases in combination with applied pressures.

Field measurements

The method is tested in a condemned school with IAQ problems. The school is situated in Gothenburg, on the west coast of Sweden, and has gone through a number of renovations in an attempt to improve the IAQ but none have been successful and the school now awaits deconstruction. The school has a crawlspace and after investigations it was concluded that the main problem originated from the crawl space and that emissions from wood preservatives is a contaminant source. Measures that has been taken to improve the IAQ is constructing ventilated floors on top of the original floor, exhaust ventilation in the crawlspace that draws air out from the crawlspace causing a negative pressure, and installing an air cleaning system. The ventilated floor is ventilated through small ducts exhausting air at roof level. Additional ventilation systems have also been installed in addition to the original ventilation system.

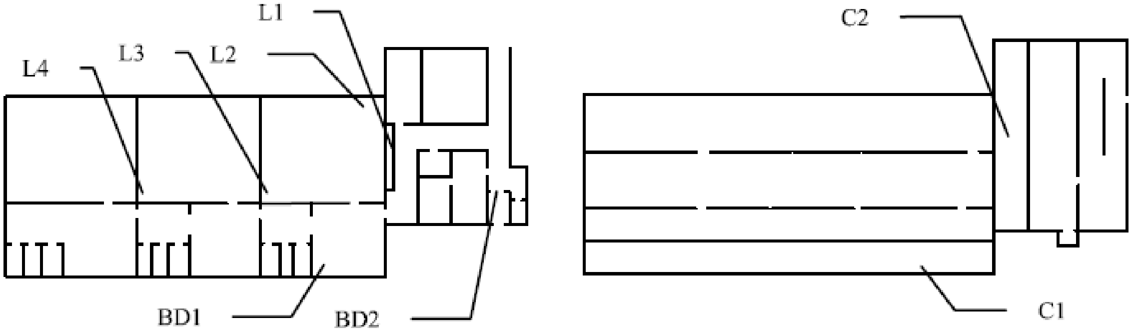

Figure 2. The figure to the left shows the floor plan with locations of CO_2 meters (L) and locations of blower door (BD1 and BD2). The figure to the right shows the crawlspace together with locations of the icebox and CO_2 meters (C1 and C2).

CO_2 meters are placed at positions L1 to L4, see Figure 2. L1 is inside a cupboard (with open doors) that contains electrical wiring from the crawlspace. L2 is close to the corner between an interior wall and the exterior wall. L3 is located by a crack in an internal wall-to-floor connection in the corner of one of the classrooms. L4 is beside one of the interior door-frames that has large cracks in the door framing.

The test procedure to detect leakages consisted of releasing CO_2 in the crawl space and detecting it at leakage positions (L1 to L4) in the classrooms. Different pressure situations were investigated (each during approximately one hour), but during the tests the crawlspace had a higher pressure than the classrooms. Pressures differences were created using blower door equipment placed either in a hatch between the indoor and the crawlspace (BD1), referred to as Case 1, or in an exterior door (BD2), referred to as Case 2. To ensure that there was an over pressure in the crawlspace, the pressure difference was measured and the fan speed of the blower door adjusted accordingly. The CO_2 was released at two different locations in the crawlspace and measured at 1-2 locations in the crawlspace, and 3-4 locations in the class rooms next to leakage positions. Leakages were found both in the middle of the building, where all incoming air is from the crawlspace, and close to external wall where some of the incoming air is outdoor air. An initial scan of leakage points was made by ocular inspection and thermography. Thermography reveals the leakage positions but not if the air is clean air from the outside or contaminated air from the crawlspace. The measurements were made during wintertime so the temperature of the crawlspace was approximately 8 °C, outdoor temperature 0 °C and the indoor temperature 20 °C.

The aim of the field measurement was to investigate **a**. the influence of the location of the CO_2 source (icebox) on the CO_2 distribution in the building, **b**. the effect of different locations of the blower door, **c**. how the pressure difference across the floor construction affects the CO_2 concentration at the leakage positions.

RESULTS OF THE FIELD INVESTIGATION

Two cases are investigated, Case 1 when the blower door is placed in the hatch down to the crawlspace (BD1, Figure 2) and Case 2 when the blower door is situated in an exterior door (BD2, Figure 2). The principle airflow paths for each case are illustrated in Figure 3.

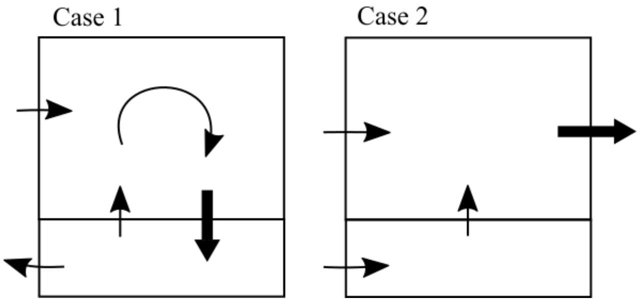

Figure 3. Shows the principle airflow paths dependent on the location of the blower door (thick arrow) where the lower rectangle represents the crawlspace and the upper rectangle represents the classrooms.

Figure 4 shows measured CO_2 concentrations for Case 1. Note that at the end of the measurement period the CO_2 meter is moved from position L3 to position L4. The results show that the concentration levels at L1 and L4 are affected by leaking air from the crawlspace (to a high degree in the cupboard at L1) whereas no significant change in concentration can be seen at L2 and L3. In Case 1 the pressure difference over the floor construction was about 35 Pa throughout the entire measurement period.

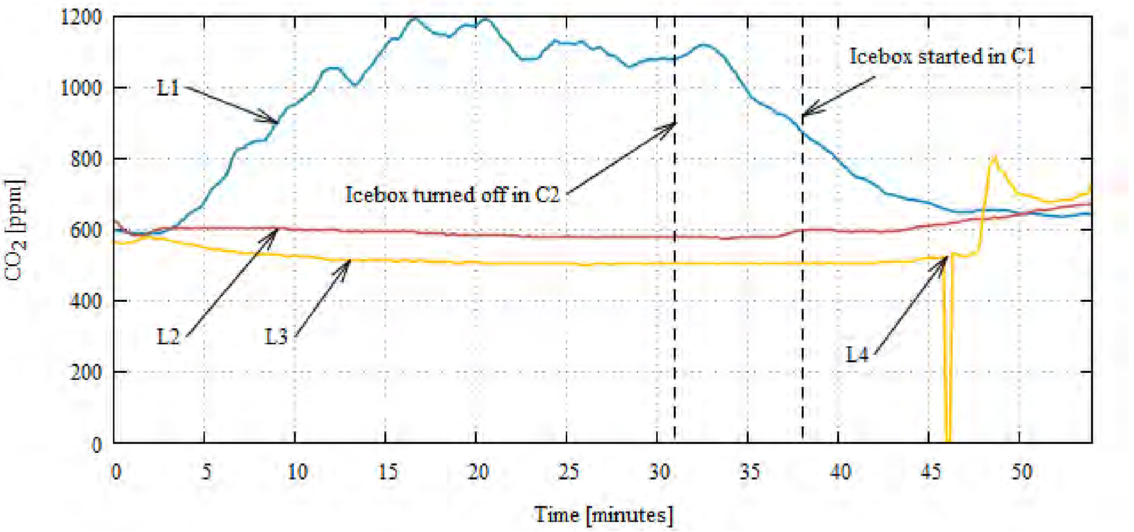

Figure 4. CO_2 concentrations measured at different locations in Case 1 (blower door in crawlspace hatch). New location for one meter at 46 minutes (from L3 to L4).

Figure 5 shows measured CO_2 concentrations for Case 2. After 21 minutes the pressure difference across the floor construction was changed from 5.7 Pa to 4.4 Pa (by decreasing the blower door fan speed), which resulted in an increase in CO_2 concentration in L1 from 1500 ppm to 2300 ppm. Concentration levels at L1 are affected by leaking air from the crawlspace, similar to Case 1. However, L2 is reaching higher concentration levels than in Case 1. One possible explanation could be that the air leakage path inside the construction is affected by the relations in pressure between indoor, crawlspace and outdoor, which will be further investigated. Measurements also showed that CO_2 concentrations were higher when the icebox was placed in the air volume directly beneath the cupboard with L1, i.e. in location C2 compared to location C1 further away.

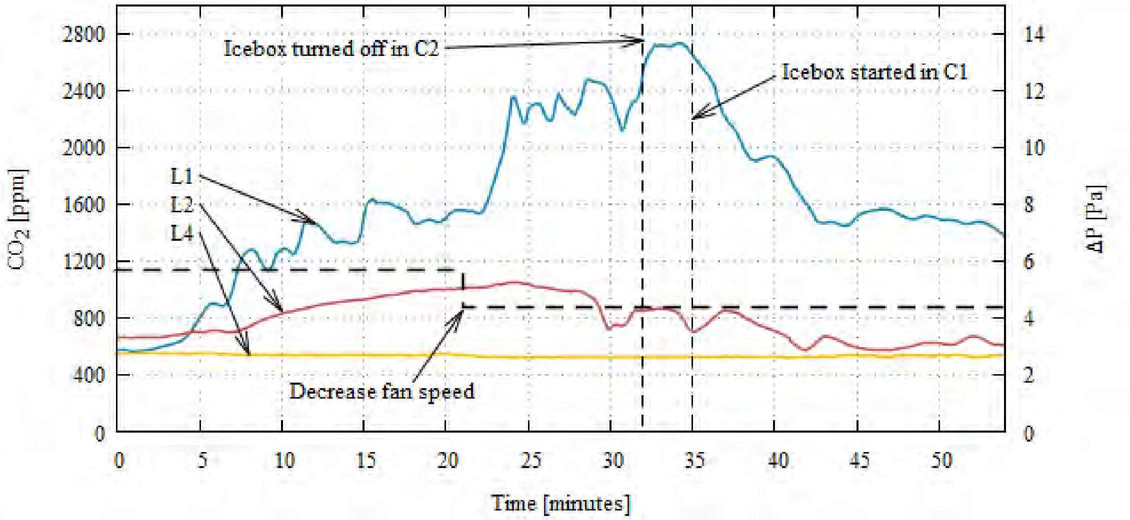

Figure 5. CO_2 concentrations measured at different locations together with the pressure difference over the floor construction in Case 2 (blower door in exterior door frame).

Different pressure differences across the floor construction will result in different CO_2 concentrations in the classrooms. A higher fan speed will then result in higher air flow rate upward through the floor but also to an under pressure in the classrooms and more outdoor air entering the building which dilutes the CO_2 concentration. It may therefore be difficult to anticipate if it is better to have a high or low pressure difference over the floor construction in order to maximize the concentrations levels at the measurement points. However, in this study it became clear that a lower pressure difference gave higher CO_2 concentrations in Case 2 with pressure difference of approximately 5 Pa (Figure 5) compared to Case 1, pressure difference 35 Pa (Figure 4). The outcome of these effects has also been confirmed in numerical simulations.

When investigating the correlation between changes such as CO_2 production, icebox location and pressure difference, the delay in response in the CO_2 concentrations at the different leakage points is a few minutes, typically three minutes. This corresponds to a leakage path of 10 m in length, 5 mm in height and at a pressure difference of 5 Pa. If the height is decreased to 4 and 3 mm, the time increases to 4 and 8 minutes respectively. This effect will be further studied in future measurements.

The method for detecting air leakages will be improved with the goal of making quantification of leakages possible. This could be done by creating a steady CO_2 production and measure the change of the mean concentration in the air volumes inside a building. Methods of dispersing CO_2 will also be investigated to make leakage detection more efficient.

CONCLUSIONS

Tracer gas measurements, using CO_2 from dry ice is used in combination with forced pressure differences in order to investigate contaminant transport in a school building. The measurements showed that:

- For the investigated cases, a lower pressure difference over the floor construction (with overpressure in the crawlspace) results in higher concentrations at measurement locations. The reason is that the crawlspace becomes less ventilated when the pressure difference is lower and therefore the leaking air has a higher concentration of CO_2.
- It is possible, with the described icebox method, to determine if the leaking air is coming from the crawlspace or from elsewhere. This method is cheaper and simpler compared to conventional tracer gas methods.

Suggested procedure for detecting air leakages from a crawlspace to the indoor environment

1. Use blower door to either pressurize the crawlspace or depressurize the indoor space.
2. Performing a leakage search to find leakages in the construction. This can for instance be done using a thermal camera.
3. Measure CO_2 background concentration prior to starting the CO_2 production in the crawlspace.
4. Add CO_2 to the crawlspace, for instance by using the icebox method presented earlier in this paper.
5. Measure CO_2 concentration at locations that in step 1 proved to have air leakage.
6. Locations with CO_2 levels high above CO_2 background concentrations will have air coming from the crawl space.

Each test step is preferably performed until steady-state conditions are reached, and at least for 15 minutes.

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