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Published in:
E3S Web of Conferences

DOI:
10.1051/e3sconf/202017207004

Published: 30/06/2020

Document Version
Publisher's PDF, also known as Version of record

Highly insulated crawl spaces with controlled minimal ventilation – proof of concept by field measurements

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Abstract. In current practices crawl spaces are typically ventilated with outdoor air. This leads very often to high relative humidity especially in the beginning of the summer, which can be problematic if the excess humidity cannot be ventilated efficiently enough. This paper introduces a crawl space concept where the crawl space is highly insulated and traditional ventilation openings are replaced by minimal mechanical exhaust ventilation set by pressure difference with the aim to prevent potential pollutants to penetrate indoors through the base floor. The concept that has been developed based on the simulation study is tested in this study with field measurements in four single family houses. Continuous measurements of relative humidity and temperature in crawl spaces and outdoor air were running more than one year in each building. The results revealed that all the crawl spaces had very low relative humidity, mostly below 75% and for very short periods close to 80% even though some of the buildings were new and construction phase moisture was drying out. The results revealed that the crawl space concept studied provided an ultimate moisture safety and can be recommended for all buildings with wooden floor.

1 Introduction

A crawl space foundation is widely used in buildings and detached houses in northern countries. Basements with a crawl space have a long tradition and it is widely used in new buildings as well despite of complicated moisture performance. In respect of radon concentrations indoors, a crawl space is an advantageous construction. The radon concentration in leakage air through a base floor decreases remarkably if the crawl space is well ventilated [1].

In addition to the ventilation of the crawl space, the pressure difference between indoors and crawl space has a role in carrying impurities indoors. A significant fraction of infiltration air can enter into the house via the crawl space [2,3], but the correlation between microbial concentrations in crawl space and indoors depends on the microbial species [2] and pressure difference across the structure [3]. According to Keskikuru et al. [4] a small under pressure compared to indoors was found to successfully prevent convective flow of radon, fungal spores and MVOCs.

Moisture problems in crawl spaces can be caused by a number of factors. Some of the problems are easy to solve; rainwater in a crawl space can be avoided by proper drainage. However, even in well-constructed crawl spaces moisture problems have occurred. In northern climates the behaviour of an outdoor air-ventilated crawl space becomes problematic in the summer, when, in the daytime, outdoor air is usually warmer and has a higher moisture content than the air in the crawl space. Thus, outdoor air can transport moisture into the crawl space and the relative humidity increases. This can be prevented by reducing the time lag between the time it takes for the temperatures of the outdoor air and the crawl space to become equal. The time lag is caused by the high heat capacity of the ground soil and foundations. In practice, to implement the described mechanism, special measures are needed such as insulating the thermal mass and applying a proper ventilation rate. In many cases such solutions have been considered too complicated as not being conceptualized and another foundation type, a slab on the ground has been recommended as a more robust solution.

The seriousness of the problem is shown by Svensson [5] reporting high relative humidity (between 80-90%) during the summer and even some condensation. In another study [6] the relative humidity in the crawl space was over 90% during the summertime.

Laukkarinen [7] was measuring five crawl spaces, where it was found that the relative humidity was over 90% between 335 to 6801 hours during one-year period depending on the crawl space type. The number of hours in a year when the relative humidity was over 80%

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varied between 3554 to 8752 in the same crawl spaces. This 80% relative humidity has often been considered as a safe side limit value for common, moisture sensitive wooden materials used in crawl spaces.

In a study by Keskikuru et al. [4] it was shown that the relative humidity in the crawl space was decreased to a level of 85% in the summer months when ground soil was covered with thermal insulation.

As there is often some organic material in the crawl space the conditions for mould growth are favourable. In favourable conditions mould growth can start very quickly. Another problem is microbial activity in the ground soil because relative humidity is often around 100 % RH and the ground soil is more or less dirty or contains organic residues. Mould growth is usually first noticed when an unpleasant smell begins to penetrate to the living spaces on the base floor.

Crawl spaces are typically ventilated by outdoor air and ventilation is natural in older buildings, but in new buildings mechanical exhaust ventilation is used. There is frequently a limited number of ventilation ducts and openings in the foundation walls, which leads to low air change rates. Due to higher awareness of energy consumption, the base floor U value has decreased nowadays to 0.17-0.10 W/m^2K. The heat losses through the base floor are smaller and, thus, a lower base floor U value leads to a colder crawl space with higher relative humidity.

The crawl space can also be left unventilated if the moisture insulation is very good [8]. The unventilated or minimal ventilation solutions have been seldomly used due to limited number of studies showing how the concept is functioning in real life conditions.

The aim of this paper is to demonstrate that moisture safe crawl spaces are possible if properly constructed. The performance of highly insulated crawl space concept with minimum controlled ventilation is studied in actual real-life conditions with long term field measurements. This highly insulated crawl space concept studied has been developed based on studies by Matilainen and Kurnitski [7-9] where it was shown that crawl space RH can be controlled by insulating the ground and applying a low ventilation rate. This principle has been developed to the modular crawl space foundation and insulation system which has been used in many buildings. In this study we report RH and temperature long-term measurements results with the aim to show that moisture safe conditions can be achieved in insulated and minimally ventilated crawl spaces.

2 Methods

2.1 Measured crawl spaces

The measured crawl spaces were located in South Sweden. The crawl spaces 2 and 3were located next to each other. Crawl space 1 had two measurement points (crawl space 1.1 and 1.2).

All the studied crawl spaces had a high thermal insulation and 0.2 mm plastic foil applied as a damp-proof membrane, which serves as a vapour and air barrier, Figure 1. The crawl space construction principle is illustrated in Figure 2. In the crawl space 2, 3 and 4 the insulation against ground soil was minimum 110 mm up to 200 mm tapered insulation and in top of that 50 mm ESP insulation. Between the insulations a plastic damp proof membrane was installed. In addition, the outer circular concrete foundation had at least 100 mm EPS insulation and in major part of the beam also 150 mm EPS insulation (inside the beam), see Figure 1. The insulation in the base floor was 170 mm and against the soil 200 mm. The exception was crawl space 1, in which the insulation was 300 mm against soil and 250 in the base floor. In general, in this concept, there has always to be more insulation against the soil than in the base floor.

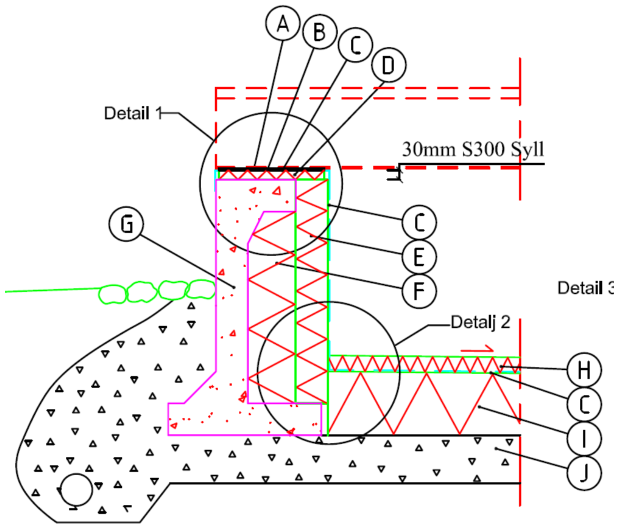

Fig. 1. The structures used in the measured crawl spaces.

A Plastic syll width 250 mm

B Soft syll insulation

C Plastic damp proof membrane

D Hard S300 insulation (closest to the beam)

E 100 mm EPS insulation

F 150 mm EPS insulation

G Outer concrete beam

H 50 mm EPS insulation

I Tapered insulation from 200 mm to minimum 110 mm

J Draining material on the flat surface minimum 150 mm

 http://doi.org/10.1051/e3sconf/202017207004

Fig. 2. Structural and insulation layers in the crawl space, the concrete circular foundation, EPS insulation and the continuous membrane from the bottom turned to the top of the foundation element.

The ventilation rate in the crawl spaces has been set with speed-controlled extract fan so that 2-3 Pa lower pressure has been achieved compared to the living spaces in the apartment, Figure 3. The average ventilation flow is about 10 litr/sec, generated by 100 mm duct fan.

Fig. 3. The minimum ventilation used in the measured crawl spaces,by mechanical ventilation.

The lower pressure was secured by air tightness of the base floor structure, crawl space structure and the minimum exhaust ventilation form the crawl space.

The air tightness of the base floor was measured in three other crawl spaces constructed similarly located in south and middle Sweden. The air tightness measurements were done by RISE with the BlowerDoor model Duct Blaster (BX61427) and with micromanometer DG-700. The measurements were done according to EN-ISO 9972:2015 method 2 but due to plastic sheet installation the under pressure was done for 25 Pa pressure difference and extrapolated to 50 Pa, which is according to the standard. The measurements are reported more detailed in RISE reports [13].

The results showed that the base floor air tightness values were between 0.05-0.31 l/sm^2 at 50 Pa, which is very good since the requirement for the passive house standard 0.3 l/sm^2. The air tightness of the crawl space structure showed values of 0.31-0.66 l/sm^2 at 50 Pa. Air tightness is important and enables to control the air flows in the crawl space.

The studied crawl space system has been in use since 2006, and there are roughly 5000 foundations currently in use. The system is typically used by timber frame modular room element producers. The estimated number of the installations in Swedish market in year 2020 is 700 crawl space systems.

2.2. Measurements

Continuously measurements of relative humidity and temperature were carried out in all crawl spaces and in addition for indoor and outdoor climate.

The measurement points were located in the middle of the crawl spaces and c.a. 15 cm under the base floor surface. The measurements were logged in every hour or in every second hour in all measured crawl spaces.

The measurements were carried out with Testo datalogger 175-H2. The measurement uncertainty is +/- 3.5% for relative humidity and +/- 0.7% for temperature. A more detailed report of measurements was given in [12].

All measurements were started just after the completion of the construction process, or latest 12 months after the completion of the construction phase. This means that some of the structures had some moisture which was drying during the measurement period.

3 Results

The relative humidity (RH) was below 75% in most of the time in crawl spaces 1 (measurement points 1.1 and 1.2), Figure 4. The winter temperature (T) in the crawl space was at its lowest close to 10^{o}C, and in the summer rather high being over 20^{o}C. Obviously the temperature and relative humidity fluctuation was much higher outdoors.

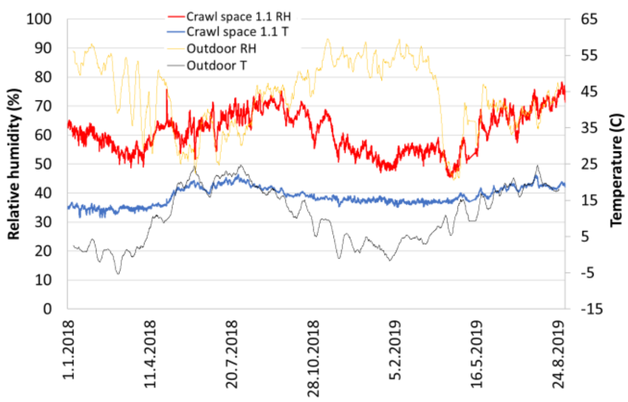

Fig. 4. Relative humidity and temperature in crawl space 1 and outdoors. The outdoor temperature and relative humidity are shown as weekly average values.

The crawl space 1 had two measurement points. There is no clear difference between their behaviour in relative humidity or in temperature conditions. This shows that the conditions were well mixed inside crawl space. In the crawl space 1 the relatively humidity is mainly below 75%, Figure 5.

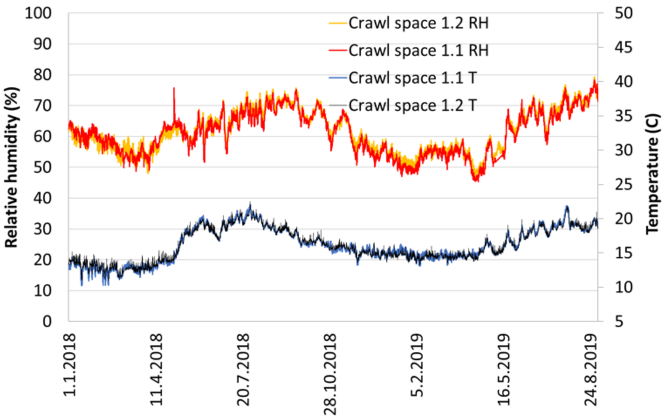

Fig. 5. Relative humidity and temperature in crawls space 1, measurement points 1 and 2.

The relative humidity in the crawl spaces 2 and 3 was most of the time below 75%, Figure 6. These crawl spaces were slightly cooler than crawl spaces 1.

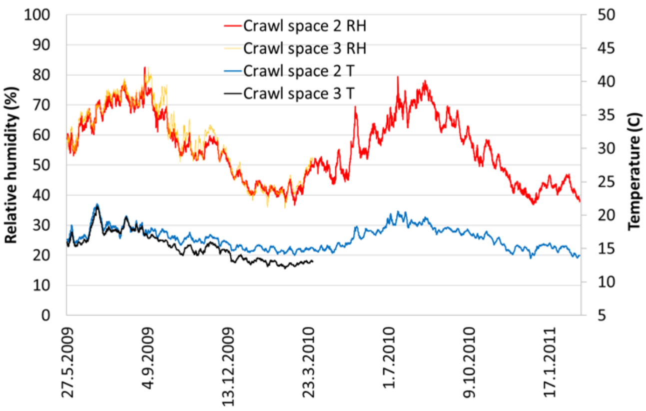

Fig. 6. Relative humidity and temperature in crawls spaces 2 and 3. There is no data after wintertime 2010 in crawl space 3

The relative humidity in crawl space 4 was also most of the time below 75% and below 80% during the measurement period in the summer and autumn, Figure 7.

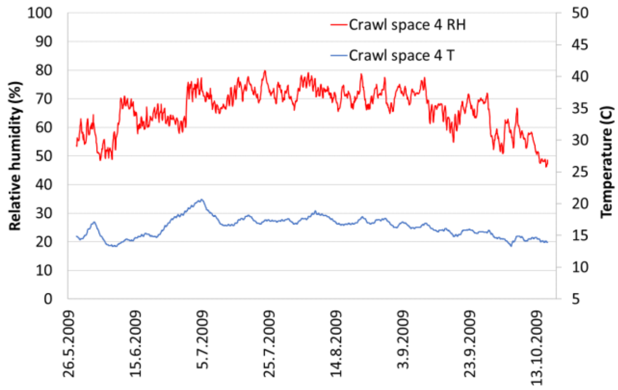

Fig.7. Relative humidity and temperature in crawls space 4.

4 Discussion and conclusion

One of the key problems in cold climate crawl spaces is high relative humidity during summer caused by a lower temperature in the crawl space compared to the outdoor air. Low temperatures in the summer are the result of a time lag in thermal behaviour which is caused by the high heat capacity of the ground soil and foundations. In principle, the time lag can be decreased by increasing the air change rate or by decreasing the heat capacity.

Many previous studies have shown that increased ventilation rate during summertime will decrease the time lag and will dry the crawl space if the ventilation rates are high enough. However, condensation might occur in some periods. In addition, in some cases it is difficult to keep the ventilation rates high enough during summer periods.

This study was focused on highly insulated crawl spaces with minimal controlled ventilation. The results showed low relative humidity levels in all measured buildings. The measured relative humidity was always under 80% and most of the time under 75%. These limit values being lower than outdoor air relative humidity represent superior moisture safety level.

Measured relative humidity results are in line with [8] what has been used for the concept development. In this simulation study, 75% relative humidity was achieved with ground insulation thermal resistance of about 5 $m^2/(W\ K)$, i.e. about 200 mm EPS insulation, therefore a good proof of concept is provided by the field measurements.

In addition, in all measured crawl spaces the winter temperatures were relatively high, over 10 °C. This is very good result since sometimes thermally well insulated crawl spaces can be rather cold during wintertime.

All the measured buildings had very good air tightness of the base floor as well as crawl space. That is important since the good air tightness together with mechanical ventilation enables the slight lower pressure of the crawl space compared to indoors. The lower pressure prevents the possible flow of impurities to indoors, especially if the base floor is not airtight. Very typically the base floors are not very airtight.

It can be concluded that the highly insulated crawl space concept with minimum controlled ventilation provided an ultimate moisture safety and can be recommended for all buildings with wooden floor. With other words, this experimentally verified crawl space concept enables construction of affordable and sustainable buildings with crawl spaces.

This research is based on measurements conducted by RISE Research Institutes of Sweden (former SP) funded by Isolergrund, which are greatly acknowledged. This research was supported by the Finnish Association of Civil Engineers RIL and Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE (grant No. 2014-2020.4.01.15-0016 funded by the European Regional Development Fund).

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