Testing of a method for insulation of masonry and lath walls in a traditional Scottish domestic building

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Project background

The presence of an existing building stock and its relatively poor energy performance put great emphasis on the upgrading of existing buildings. The basic fabric of these buildings: walls, roofs, floors and services require upgrading to reach present and future increasing standards of thermal performance. In the Scottish context, this research focuses on existing load-bearing masonry construction with internal plastered lath lining.

Aim and scope

The main aim of this research project is to develop and test the feasibility of a method of insulating an existing house whilst maintaining its original architectural features. The project comprised the following phases: Phase 1 - Building selection and site surveying; Phase 2 - Testing method preparation; Phase 3 - Site preparation; Phase 4 - Application, and Phase 5 - Remedial work.

An overview of the method and product applied

The method involved using water blown foam, developed by Canadian company Icynene Inc. This is the first time such insulation has been used in a historic building in Scotland. The water blown foam was created specifically for injecting into delicate structures. The foam expands slowly, putting little pressure on the fragile inner wall and, as it is 100 percent water blown, it contains no harmful blowing agents. Additionally, through its open cell structure, the foam will allow the wall to breathe which will assist in controlling moisture movement.

Phase 1: Site surveying

After visiting many buildings proposed by local house owners, the project team found a suitable building which met the criteria of a historic building with vulnerable construction details. The specifications required great attention as this construction type is difficult to insulate and insulation companies have not yet offered an adequate solution.

Phase 2: Testing method preparation

Prior to the trial, discussions took place between the researchers, local architects and the company who agreed to supply the insulation material and apply it by using the proposed method agreed by the team. The agreed method was tested in a workshop before its application on the real wall (Pictures 1 and 2).

Picture 1. Trial in the workshop

Picture 2. Observation of the trial test

Phase 3 -Site preparation

Before the arrival of the team in charge of implementing the insulation, the site was prepared. This involved the installation of floor boards and lighting in the loft, and the removal of the skirting boards and all the dust that has gathered in the wall cavity since building was built (Picture 3).

Picture 3. Floor covering and lighting installed for safety and easy access to the loft

Other preparations involved the carpet removal in the room that will be insulated, the covering of the floors and all original features such as fire place and windows.

Debris behind the skirtings was removed by using industrial vacuum cleaner to leave the cavity wall as clean as possible to avoid any thermal bridging.

Phase 4 – Application

On arrival at the house, the team was satisfied with the site preparation and examined the condition of the existing lath and plaster lining. As it was possible to move the wall at the bottom, in and out, by 30mm with very little force, this indicated that the bottom of the wall and the studs were no longer fixed (by dooks) to the masonry.

Using fibreglass probes, the draw cords were inserted from the attic area down to the open void where the skirting boards would be positioned. The introduction cords were abounded later on as the trial showed that they were inappropriate. The draw cords were attached to the 10mm polyurethane pipes which were pulled down and then retracted 200mm, and secured. A pipe was inserted between each stud (Picture 4). As the site supply of polyurethane pipe ran out, the only locally available pipe of the same diameter was a PVC pipe that was used to four bays. This type of pipe appeared to be more difficult to work with then the previous one.

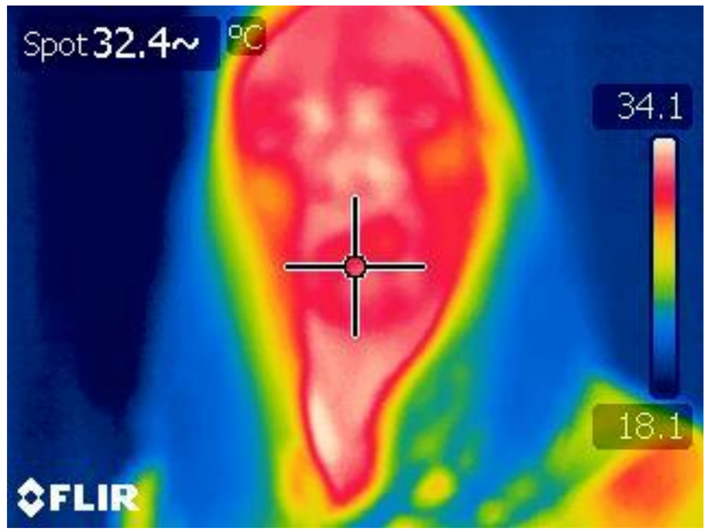
Picture 4. Pipes attached to cords

As the pipes were installed, debris was falling down when disturbed. To ensure no thermal bridge within the cavity was caused, which could lead to damp problems in the future, it was decided to clean the cavity by moving the fibreglass probes around to dislodge trapped debris, assisted by blowing air into the cavity. Approximately a pale full of debris was removed, which consisted of plaster lumps, fine dust and wooden twigs, presumably put there by birds making nests (Picture 5). The void was then cleaned by vacuum and brushing.

Picture 5. Sample of debris removed from the wall during the trial despite the cleaning prior to the start

Once the cavity was re-inspected with the endoscope and deemed to be free of loose debris, spray-foam was applied to seal the base void. The spray-foam added some rigidity, and bonded well to the surrounding areas within the void. The equipment was changed over from the spray-foam material to the pour-foam material, and samples taken to test the rate of expansion. The pour-foam was then injected down the preinstalled pipes in durations of 10 seconds. The pipes were withdrawn 500 mm after each injection and cleaned by blowing air through them. The process of injecting alternate bays was adopted to ensure the least possible outward pressure to the wall.

The wall was monitored at all times for movement. An infra-red camera available on site gave some indication where the material was injected, but this was not conclusive and only showed the body of the pour-foam in liquid form and not the areas in which the expansion took place (Picture 6). The PVC pipe would not take a second injection without blocking, which in turn caused a blockage in the gun, requiring replacement with polyurethane pipes. The process was repeated until the pour-foam was visible in the attic space (Picture 7).



Picture 6. Monitoring the foam expansion with infra-red camera

Picture 7. Foam seen at the eave level

Picture 8. Insulating the wall below the window

Surface below the window was insulated with the spray-foam (Picture 8).

Data collection

1. Monitoring the temperature and humidity.

Five months before the insulation was implemented, the house was equipped with data loggers to monitor the temperature and humidity in various parts of the house including the loft, the kitchen, the lobby and the cavity-wall in which the insulation was to be injected. External temperature and humidity were also monitored. It was planned to place the data loggers at both insulation edges, i.e. close to the lath and plaster and close to the sandstone.

After the preparation of the devices to be inserted in the cavity wall, it was found that the cavity width varies and that the 70mm cavity space measured at the start of the study was the maximum width. Therefore, it was not possible to introduce the wooden devices holding the two data loggers into the cavity, but only one sensor.

2. Data collection process

The recording started in March 2011, three months before the insulation implementation, and ended in June 2012. It was assumed that 15 months are enough to study the temperature and moisture migration through a wall and specifically through the insulation material that was applied in August 2011.

Simulation of moisture movement through the sandstone wall

Insulation can be fitted inside the air gap of traditional stone and lath and plaster walls in order to improve their thermal performance. There are, however, some concerns about the effect that the insulation will have on moisture movement through the wall. A CFD model of a wall, with and without insulation, has been developed in ANSYS Fluent 13.0 in order to establish what effect the insulation has on the moisture migration.

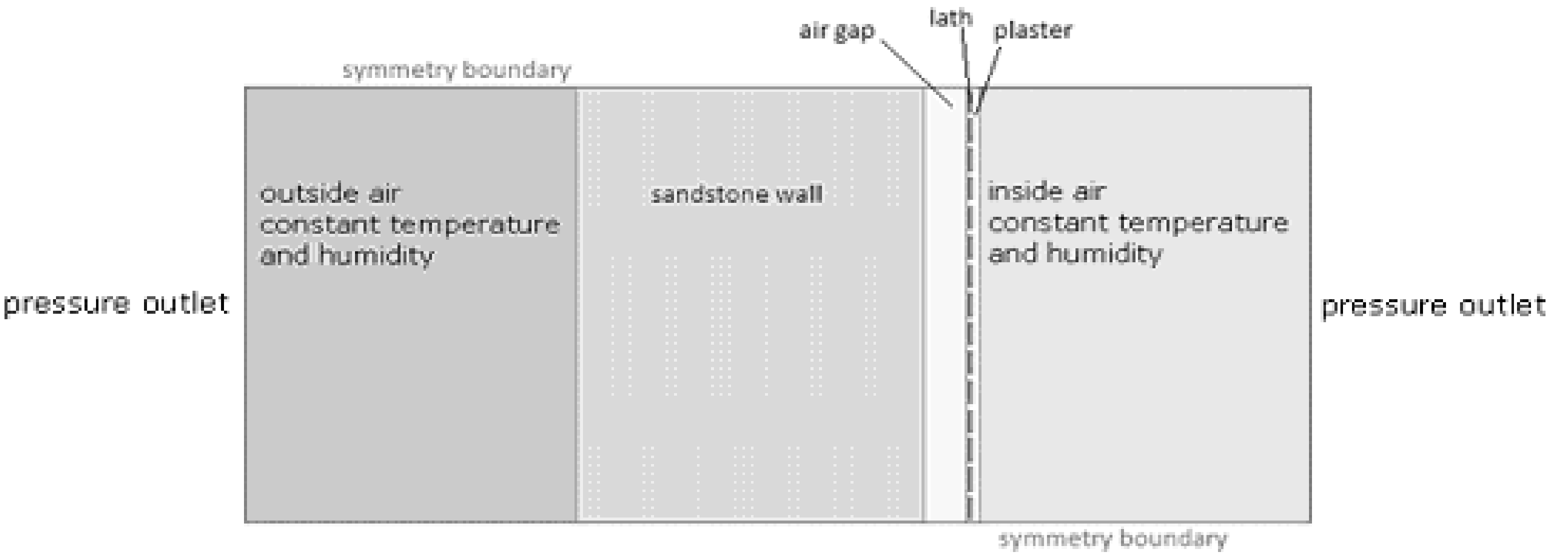


Figure 1. Simulation set up

Error! Reference source not found. shows the geometry and boundary conditions used in the simulation. A 2D simulation was chosen because the results will be more widely applicable than if a 3D simulation of a particular building was carried out. Another significant advantage of 2D simulations is that they are less time consuming to set up and run. This allowed more cases to be simulated, giving a much clearer picture of the effect of the insulation.

The section of wall modelled is representative of a section of any wall of similar geometry in regions that are sufficiently far enough away from floors, windows, doors, ceilings or other discontinuities. In the simulations it is assumed that moisture moves only in the x-direction as the wall is sufficiently large in the y-direction and moisture movement in that direction only occurs in small sections near the top and bottom of the wall.

Cases simulated

To ensure that the conditions for which the simulations were run were realistic and represented the entire range of conditions that were likely to occur, temperature and humidity data measured at the site was analysed to find standard and extreme conditions.

The measured data sets gave the temperature and humidity outside the wall, in the air gap and inside the room for around 3.5 months before the wall was insulated and 4 months after the wall was insulated. The data was analysed to find the maximum, minimum and mode values of the temperature and humidity before and after the wall was insulated inside the room, in the air gap and outside. Since the mode value of humidity or temperature occurred multiple times for each position, a set of conditions for the simulation was selected by taking the first time and date for which the median value of the other quantity (temperature or humidity) occurred. As the simulations did not converge for the air gap mode temperature (representative) conditions measured after the wall was insulted, no results have been obtained for this case.

Comparison of simulation results and measured data

Simulations were run for the outside and inside conditions, and the results obtained for air gap temperature and humidity were compared with the measured values. When setting up the simulations the mass fraction of water vapour in the air needed to be input, rather than the relative humidity.

Values for mass fraction were calculated from the relative humidity data using data from 281 Transport Information Service 2012 using linear interpolation. As the results from the simulations can be displayed in terms of relative humidity, it was possible to check that the mass fraction of water vapour had been calculated correctly. When checking the relative humidity values it became apparent that the linear interpolation method used to calculate the mass fraction values was leading to some differences between the simulation and measured relative humidity values. For cases where the difference between the simulation and measured values was greater than 1% relative humidity, a trial and improvement method was used to change the mass fraction values until the difference between the simulation and measured values was less than 1%.

For the wall without insulation 61% of the cases simulated had less than 1^{o}C temperature difference between the measured and average simulated air gap temperatures. The maximum difference was 4.0^{o}C. It should, however, be noted that the temperature varies across the air gap so the temperature and humidity measured by the sensor is likely to differ from the air gap average and will depend on the exact position of the sensor. There are only two cases for which the measured temperature does not fall between the maximum and minimum air gap temperatures of the simulation. In both of these cases the air gap temperatures in the simulation are higher than the measured temperatures.

The simulation and measured air gap temperatures are compared for a wall with insulation. The variation between the simulation results and the measured results are greater for the insulated wall with only 29% of cases having a difference of less than 1^{o}C between the average air gap temperature and the measured temperature. The measured temperature did not fall between the maximum and minimum simulated air gap temperatures for 41% of the simulated cases. The air gap temperatures in the simulations were typically higher than the measured values.

The difference between the simulated and measured relative humidity values is typically higher than the difference between the simulated and measured temperature values with only one case for which there is a less than 1% difference between the simulation and measured values of relative humidity. As the variation of relative humidity over the air gap is much larger than the variation of temperature over the air gap, it is expected that the difference between the average values and the measured values will be larger. In 56% of the cases the measured value fell within the range of simulated values.

The simulation and measured values of air gap relative humidity are compared for an insulated wall. For this case, as well as for the wall without insulation, the difference between the simulated and measured relative humidity values is typically higher than the difference between the simulated and measured temperature values.

There were no cases for which there was a less than 1% difference between the simulation and measured values of relative humidity. For the insulated wall the measured value of relative humidity fell within the range of relative humidity values calculated for the air gap in the simulation 29% of the time.

The agreement between the simulation and measured results is generally reasonable, although there are some cases for which there is a significant difference between the measured and simulation results. The agreement between the measured and simulation results was generally better for the wall without insulation than the insulated wall.

The effect of insulation on the moisture in the wall

Since it has been shown that there is reasonable agreement between the model and simulation results, simulations were run to try to establish the effect of the insulation on the moisture movement through the wall. The sets of inside and outside conditions were sorted by outside temperature and each set of conditions was assigned a case number.

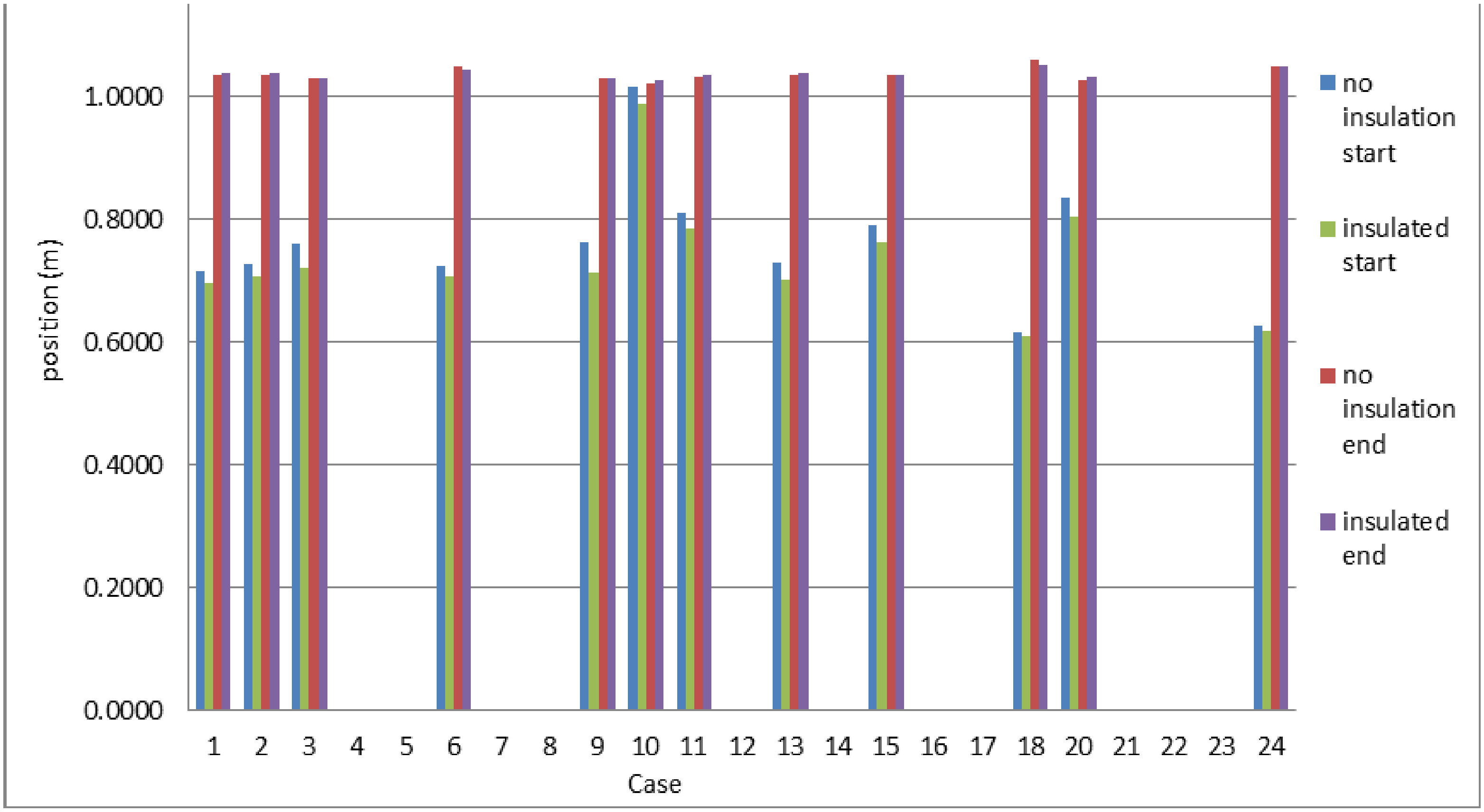


Figure 1- Comparison of start and end points of the region where moisture forms for insulated walls and walls without insulation

The places where condensation forms are compared for a wall with no insulation and an insulated wall. For all of the cases where condensation formed in the insulated wall it also formed in the wall with no insulation. However the exact position of the start and end points of the region where condensation formed differed. Figure 1 compares the start and end points of the region where condensation formed for a wall without insulation and an insulated wall. Typically the region where moisture formed was larger for the insulated wall than it was for the wall with no insulation.

Greater insight can be gained into how the insulation is affecting the movement of moisture through the wall by considering how mass fraction of H_2O, temperature and relative humidity vary with position in the wall for the insulated walls and walls without insulation.

Figure 3 is an example of a plot showing the variation of mass fraction of H2O for a wall without insulation and an insulated wall. The plot in Figure 3 is for case 1, but the same trends are shown by the other cases. It can be seen from Figure 3 that the presence of insulation has no effect on the distribution of mass fraction of H2O in the wall. Figure 2 however, shows that position where condensation forms is dependent on whether or not the wall is insulated. This means that the relative humidity variation through the wall must be affected by whether or not the wall is insulated. Figure 4 is an example of a plot showing the variation of relative humidity through the wall for an insulated wall and a wall without insulation. The plot in Figure 4 is again for case 1 but the same trends are shown by the other cases. It can be seen from Figure 4 that the variation in relative humidity in the sandstone and across the air gap is larger when the wall is insulated. This is explained by considering the effect of the insulation on the temperature profile through the wall.

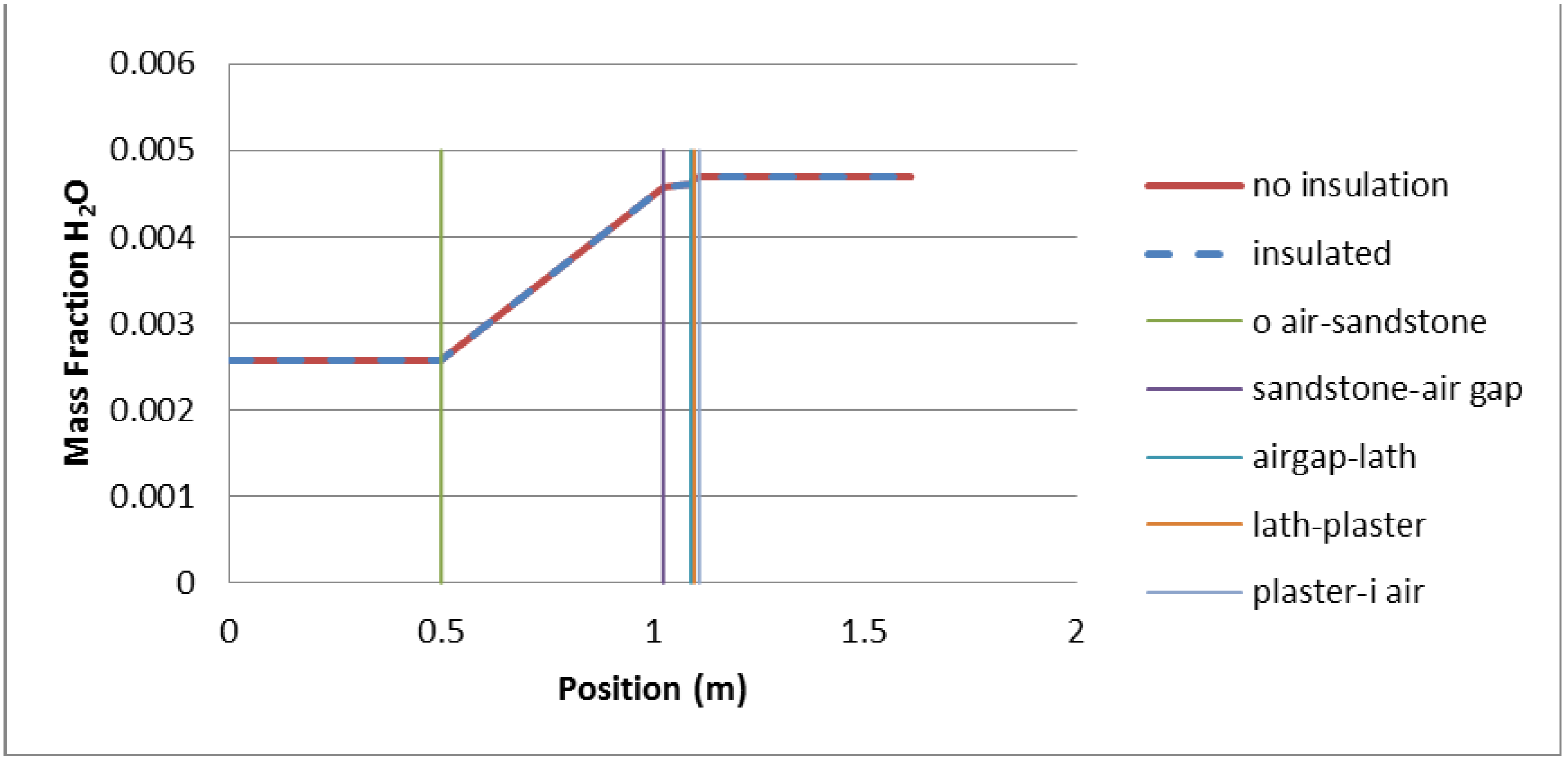


Figure 1- Example of plot of the variation of mass fraction H_2O through the wall (case 1)

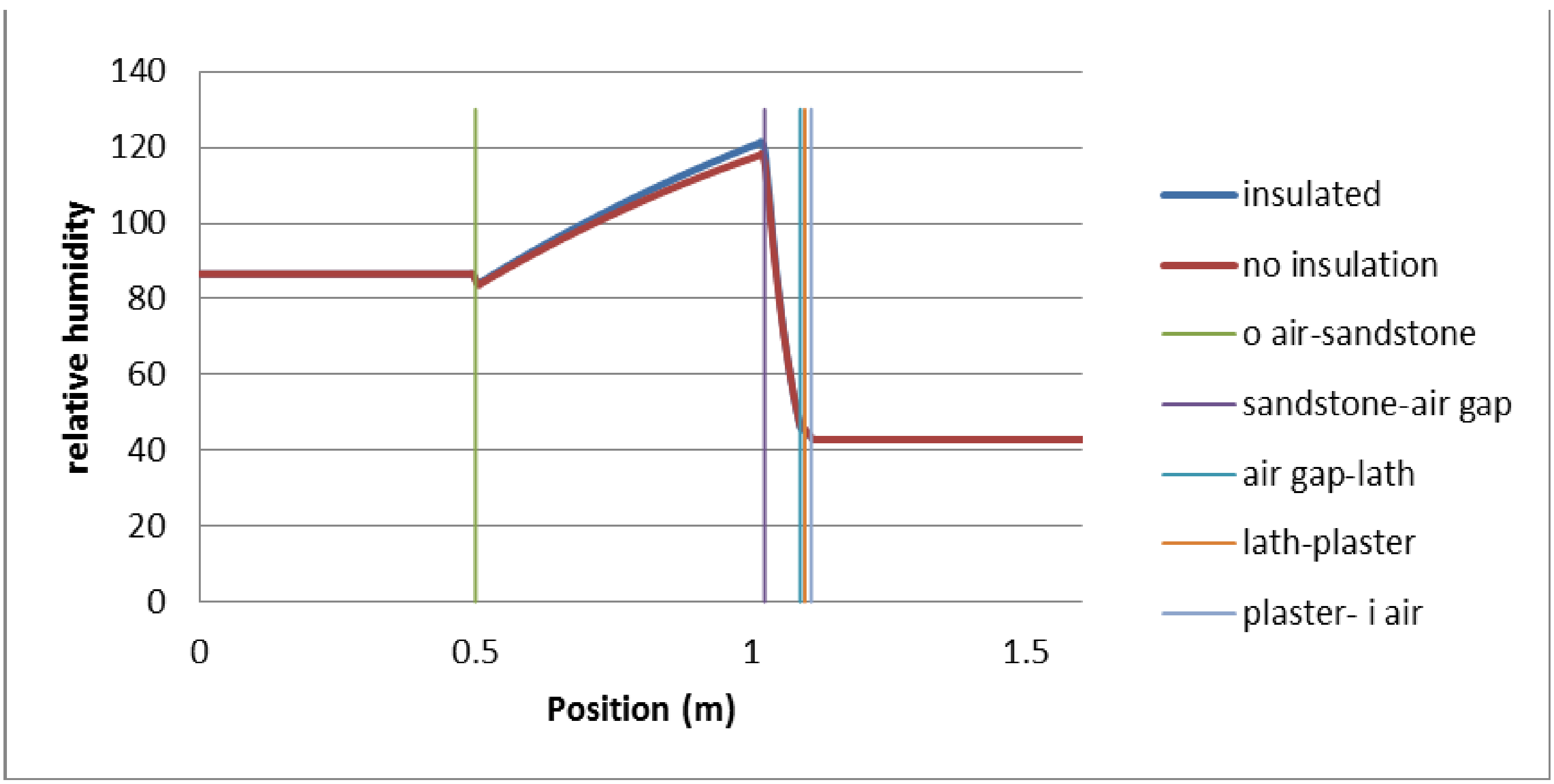


Figure 2- Example of plot of the variation of relative humidity through the wall (case 1)

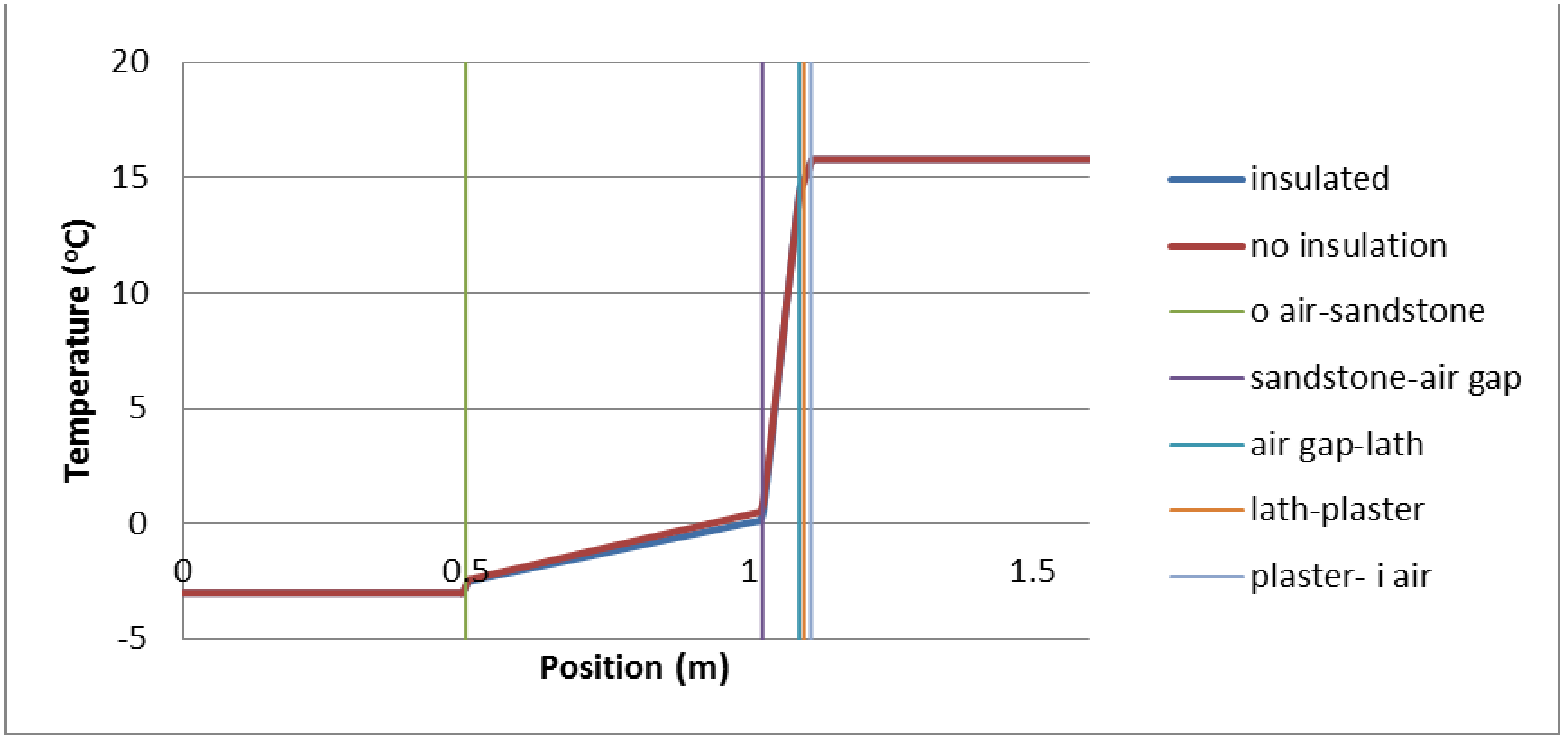


Figure 1- Example of plot of the variation of temperature through the wall (case 1)

Figure 1 shows how the temperature varies through an insulated wall and a wall without insulation for case 1. It can be seen that the temperature increase from the outside edge of the sandstone to the inside edge of the sandstone is reduced and the temperature increase over the air gap is increased when the wall is insulated. It is this difference in temperature profile that is responsible for the changing location of where moisture forms. As relative humidity is a function of temperature as well as mass fraction of H_2O, by changing the variation in temperature throughout the wall, the insulation is changing the position of the region where moisture forms.

Conclusions

A CFD model has been developed which allows the effect of insulation on the moisture movement through and formation of condensation in a wall to be studied. Simulations were run with and without insulation in the air gap of the wall and the results were compared.

The results from the simulations suggest that the insulation had a negligible effect on the movement of water vapour through the wall. However, it did affect the temperature profile of the wall. As relative humidity and dew point, the point at which condensation forms, are functions of mass fraction of water and temperature, the change in temperature due to the presence of insulation affects where the condensation forms, despite the insulation not having an effect on the distribution of water vapour in the wall.

Where condensation formed, it was present both when the wall had and did not have insulation. Typically, condensation formed in the sandstone and in the air gap close to the sandstone. The start and end positions of the region in which condensation formed were affected by whether or not insulation was present. Typically, when insulation was present, the region in which condensation formed was larger than when the wall was not insulated. However, the differences were not large.

As the simulations were static, they only showed the equilibrium state for given outside and inside temperature and humidity conditions. Comparison of the results from the static simulations with measured data suggested that inside and outside temperature conditions typically varied over a shorter period than it took to achieve equilibrium conditions in the air gap. Ideally, time stepped simulations would be run in which the inside and outside conditions vary with time and the resulting variation of air gap conditions is calculated. The disadvantage of running time stepped simulations is that the results from them would be less widely applicable.

Another important feature of the system that was not captured in the simulations is the circulation of air in the air gap of the wall. Before the wall was insulated there would have been significant circulation of air inside the air gap. This circulation of air will have affected the temperature and humidity inside the air gap. In the simulations the air was static which will have resulted in the temperature difference across the air gap being far larger than that which would actually occur when the air is free to move. It was not possible to model air circulation in the air gap as this is strongly dependent on the exact geometry and condition of the building and the external weather conditions, including wind speed and temperature. The results from a 3D simulation of a building would only apply to that particular building for the weather conditions simulated. This is one of the reasons why 2D static simulations were carried out as the results from these are much more generally applicable.

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