# Timber-Frame Walls: Feasible with a Damaged Vapor Barrier?

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## ABSTRACT

*A ventilated cavity is usually considered good practice for removing moisture behind the cladding of timber-framed walls. Timber-frame walls with no cavity are a logical alternative, as they are slimmer and less expensive to produce and reduce the risk of a two-sided fire behind the cladding.*

*To investigate the possibilities, full-sized wall elements with wooden cladding and different cavity design, type of cladding, and type of wind barrier were exposed to natural climate on the outside and to a humid indoor climate on the inside. During the exposure period, parts of the vapor barrier were removed in some of the elements to simulate damaged vapor barriers. The condition of the wind barriers of elements with intact vapor barriers was inspected from the inside after four years of exposure.*

*This paper presents results with emphasis on the moisture conditions behind the wind barrier. It was found that the specific damages made to the vapor barrier as part of the test did not have any provable effect on the moisture content. In general, elements with an intact vapor barrier did not show a critical moisture content at the wind barrier after four years of exposure.*


## INTRODUCTION

A ventilated cavity behind the cladding in timber-frame walls is usually considered good practice for removing moisture from the construction. The primary function of the cavity is to shed exterior moisture; secondarily, it is intended to remove the small amount of moisture that is not held back by the vapor barrier. However, moisture is only removed from the construction by ventilating it with air having a lower moisture content than that corresponding to equilibrium with the materials present in the cavity. Ventilation with humid air might instead add moisture to the construction (TenWolde et al. 1995).

Geving et al. (2006) concluded that nonventilated cavities may behave better than ventilated cavities in façades, exposed to driving rain only to a small degree. On the other hand, ventilated cavities are still recommended as the best solution in Norway (Kvande et al. 2007).

In Denmark, most houses suitable for use throughout the year are made of brick or concrete. Since houses made of wood (i.e., with external walls of timber-frame construction) are becoming more common in Denmark as an economic alternative to houses made of bricks, knowledge about the behavior of such houses is needed. In the other Nordic countries, houses made of wood have been built for centuries but experiences cannot be transferred directly because the Danish climate is somewhat different.

External walls of houses made of wood in Denmark normally contains the following control layers

- Wooden cladding, which acts as a rain barrier.
- Ventilated cavity to shed external moisture that penetrates the cladding. The cladding and the cavity in combination act as a two-step preventative.
- Wind barrier to ensure that the insulating property of the thermal insulation layer is not reduced by convection. The wind barrier is often a gypsum board treated for water resistance.

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- Thermal insulation layer, normally made of mineral wool. The thermal insulation is placed inside the timber-frame construction.
- Vapor barrier, which also acts as an air barrier. The primary function of the vapor barrier is to ensure that moisture from the inside is prevented from entering the structure. The vapor barrier is normally mounted 1/3 inside the thermal insulation layer (seen from the indoor side) to protect it from being perforated.

A previous study carried out at the Danish Building Research Institute (SBi) contained full-scale tests with wall elements with wooden claddings and a 25 mm cavity depth. It was concluded that 285 mm of mineral wool, which satisfies the increased demands to the thermal performance of external walls, does not give rise to problematic moisture conditions in the construction (Andersen et al. 2002; Hansen et al. 2002; Stang et al. 2002).

A new set of elements were prepared to further investigate the importance of the ventilation openings. Some of these results, presented in a previous paper from this study (de Place Hansen and Brandt 2009), suggested that timber-frame walls with a cavity behind the wooden cladding perform well independent of whether the cavity is ventilated or not. However, if a nonventilated cavity is used, the type of wind barrier is important. Façade elements without a cavity should be avoided, as they give rise to a moisture content that is higher than the level considered dangerous with respect to potential mold growth.

This paper presents further results from full-scale tests, including measurements of elements after deliberately making holes in the vapor barrier, as well as inspection of the wind barrier from the inside after four years of exposure.

## EXPERIMENTAL

Full-sized wall elements in a test building located at SBi were exposed to natural climate on the outside and to a humid indoor climate on the inside (22°C, 60% RH). A humid indoor climate was chosen to exaggerate the exposure compared with real conditions, thereby making it easier to detect differences in behavior between the tested elements. On the other hand, in some cases people live in a moist indoor environment (e.g., if many people live together and they do not air the rooms, or if the washing is dried indoors). Temperature and moisture conditions inside the wall elements and the relevant climate parameters had been recorded since September 2005.

Test specimens were 18 different wall elements with 285 mm of mineral wool as thermal insulation. The test parameters included ventilated cavity/nonventilated cavity/no cavity behind the cladding, type of wind barrier, and type of cladding. The cavity was normally 12 mm deep. A 9 mm exterior moisture-resistant gypsum board was used as wind barrier in most cases, but oriented strand board, cement-bonded particle board, etc., also were included in the study.

The elements discussed in this article all had a 0.15 mm polyethylene vapor barrier with a nominal water vapor diffusion resistance of 375 GPa·m$^2$·s/kg and a 13 mm interior paper-faced gypsum board as inner cladding. The vapor barrier was either placed behind the inner cladding (Figure 1A) or at the outdoor side of a second gypsum board placed 45 mm or 95 mm inside the thermal insulation material (Figure 1B), which is the more common in Denmark to protect the vapor barrier from being penetrated.

The dimensions of the wall elements were 350 mm in thickness × 584 mm in width × 2683 mm in height. Two replicates were made of each element. The elements were installed in the south and the north façades, respectively, so identical elements were tested on both façades of a test building at SBi, in total 36 elements.

Further description of the design of the elements and the test building are given in de Place Hansen and Brandt (2009).

### Inspection of Wind Barrier from the Inside

Some of the elements were inspected from the inside in order to study the moisture conditions at the wind barrier. Elements with an intact vapor barrier were the prime targets, because they were supposed not to show moisture damages. The inspection took place in November 2009 after about four years of exposure. Before inspection, the inner cladding, the vapor barrier and part of the thermal insulation were removed (Figure 2).

The vapor barrier was completely removed for two elements in order to study how the elements would behave without a vapor barrier during the winter 2009/2010 (one element with a nonventilated cavity facing north and one element without a cavity facing south). In the other cases, only a part of the vapor barrier was opened along the edge of the element (Figure 3A) or cut open (Figure 3B). After the inspection, the openings were sealed with special vapor barrier tape to restore the elements for the continued measurements.

The elements were inspected visually and the moisture content in the timber parts of the element next to the wind barrier was measured by means of a moisture meter.

## MEASUREMENTS

Moisture content in the elements was measured by means of moisture measuring dowels according to NT Build 420 (1993). Moisture measuring dowels were beech wood dowels (diameter 10 mm) with two electrodes embedded (Brandt and Hansen 1999). The electrical resistance grows very high when wood becomes dry; hence the lower detection limit of the moisture content measurement was 11% by weight with the applied data logger. The moisture contents were recorded every 12 hours.

Temperatures were measured with thermistors placed close to the moisture measuring dowels. The temperature measurements were recorded every 12 hours. The positions of the moisture and temperature sensors are shown in Figure 4. Sensors were placed 200 mm from the bottom of the element.

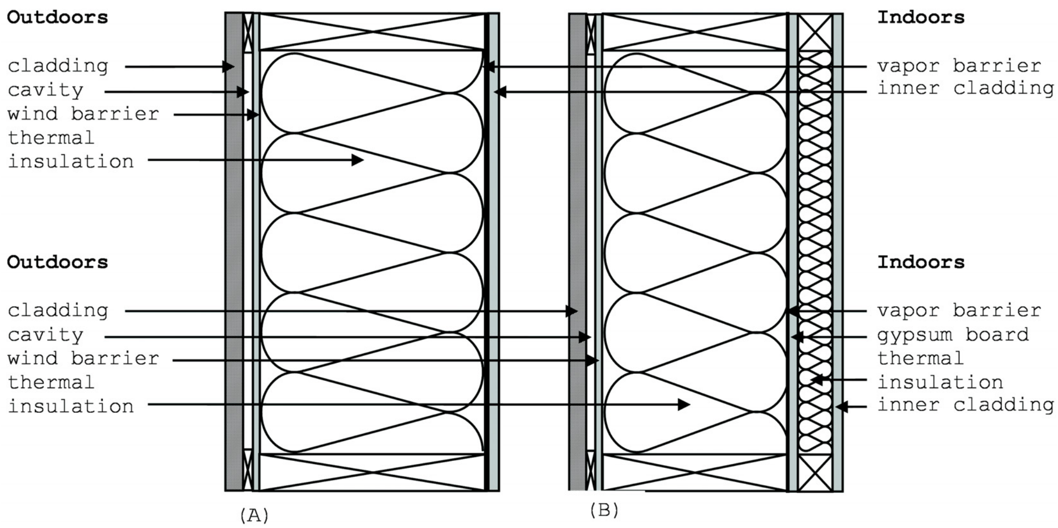



***Figure 1*** *Horizontal cross section of typical elements; outdoor side at left. (A) Element with façade cladding, cavity, wind barrier (9 mm moisture-resistant gypsum board), 285 mm of thermal insulation material, vapor barrier, and inner cladding (13 mm interior, paper-faced gypsum board). (B) Element with façade cladding, cavity, wind barrier, 190 mm or 240 mm of thermal insulation material, vapor barrier, gypsum board (13 mm interior, paper-faced gypsum board), 95 mm or 45 mm of thermal insulation material, and inner cladding.*

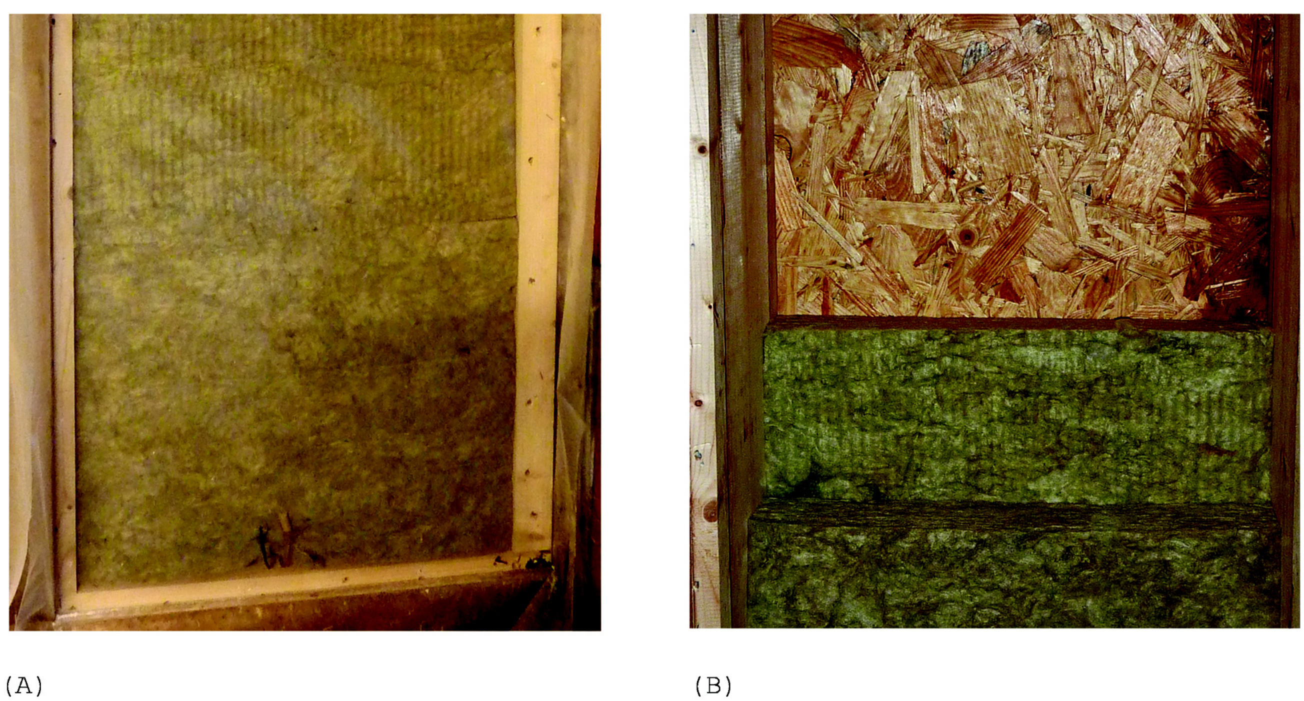



***Figure 2*** *Inspection of element (A) after removing the inner cladding showing the vapor barrier, and (B) after removing part of the thermal insulation material showing the wind barrier.*

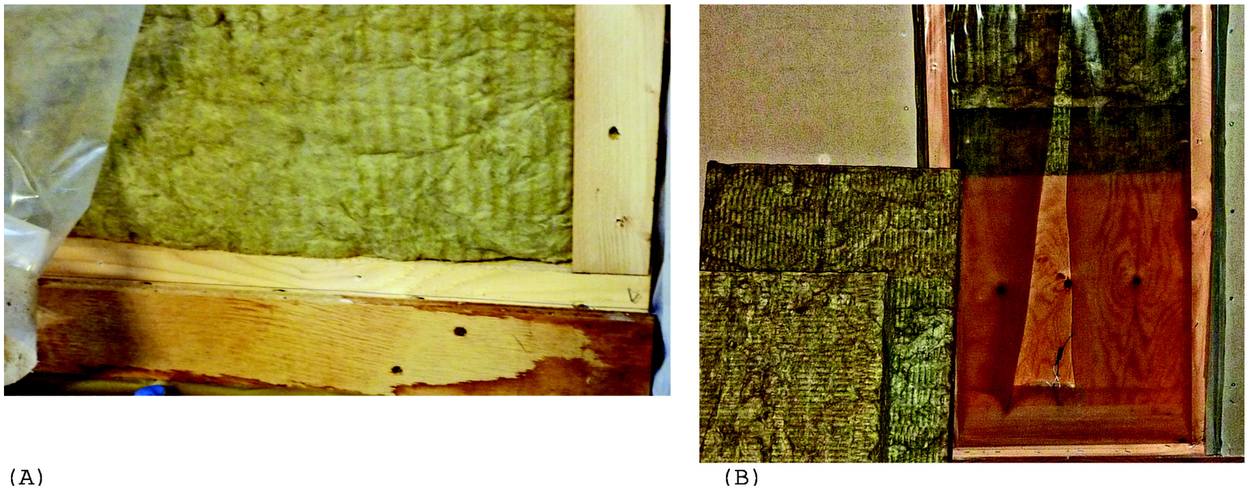



***Figure 3*** *Elements where the vapor barrier was opened (A) along the edge, or (B) by making a cut.*

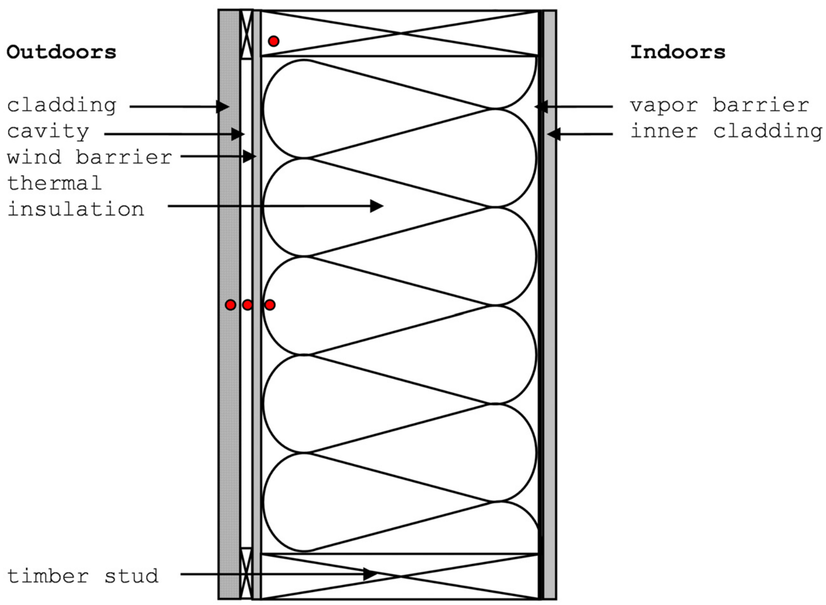



***Figure 4*** *Horizontal cross section of an element with a cavity and horizontal weatherboard as cladding, outdoor side at left. Dots indicate position of the moisture and temperature sensors: in the wooden cladding, in the cavity, in the thermal insulation material adjacent to the wind barrier, and in the studs. In some cases, sensors were only positioned in the cladding and behind the wind barrier.*

In three elements, additional sensors were placed in the cladding and in the cavity 200 mm from the top of the element and in the middle of the element.

### Damaged or Imperfect Vapor Barrier

The vapor barrier was mounted carefully in order to ensure an airtight inner part of the elements. In practice, a vapor barrier is often damaged either at mounting or later when occupants install additional lamps, etc. Therefore, in the autumn of 2008, holes were made in the vapor barriers in six elements representing an open cladding (horizontally lapped boarding; elements 1, 4, and 11) and a tight cladding (horizontal weatherboard, elements 2, 6, and 10) (Figure 5) and different types of cavity (ventilated, nonventilated, no cavity). Elements 1, 2, 4, 6, and 11 were designed as shown in Figure 1B, with the vapor barrier behind 45 mm or 95 mm of thermal insulation, representing the typical design of timber-frame walls in Denmark. Element 10 was designed as shown in Figure 1A, with the vapor barrier right behind the inner cladding.

(A) (B)

***Figure 5*** *Elements with (A) open cladding (horizontally lapped boarding) and (B) tight cladding (horizontal weatherboard).*

With a water vapor permeability of 0.003 kg/($m^2$·s·GPa) for the vapor barrier and 2 kg/($m^2$·s·GPa) for the inner cladding (13 mm paper-faced gypsum board), the moisture transfer could be calculated. With indoor conditions of 22°C and 60% RH and outdoor conditions of 5°C and 80% RH, only 0.28 g moisture will pass through the vapor barrier in 24 hours whereas 188 g moisture will pass through the inner cladding without a vapor barrier.

By removing 1/40 of the vapor barrier, 1/40 × 188 g = 4.7 g moisture would pass through the element in 24 hours instead of 0.28 g (intact vapor barrier), or 16 times more. This simulated a damaged or imperfectly mounted vapor barrier. However, the damaged vapor barrier in combination with the gypsum board still had an average water vapor diffusion resistance of about 20 (GPa·$m^2$·s)/kg. The different types of wind barriers had water vapor diffusion resistances of 0.4 (GPa·$m^2$·s)/kg to 4 (GPa·$m^2$·s)/kg. This meant that there was still a favorable ratio between the water vapor resistance of the inside cladding and the wind barrier. Provided that convection could be avoided, this meant that moisture problems should not occur.

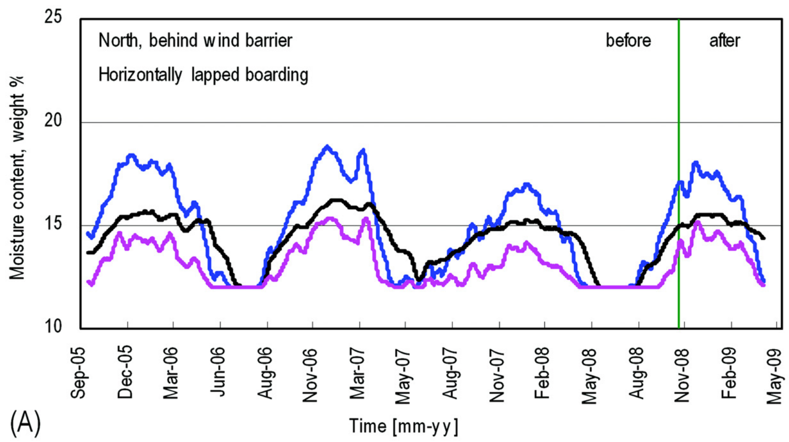
In each element, four holes with a diameter of 110 mm were made, which equalled 1/40 of the area of an element. The holes were placed along the centre line of the element, with an internal distance of about 500 mm and with 500 mm to the top and bottom edge of the element. In some cases, only a piece of the inner cladding had to be removed to reach the vapor barrier; in other cases, the vapor barrier was placed in front of or behind a second gypsum board placed behind 45 mm or 95 mm of thermal insulation material (seen from the indoor side; see Figure 1). After removing the vapor barrier, the element was restored (i.e. the thermal insulation material and the pieces of gypsum board were put back in place). The inner cladding was restored by sealing the cut around the pieces of gypsum board as seen in Figure 6.


***Figure 6*** *Elements with restored inner cladding after removing four pieces of vapor barrier.*

## RESULTS

For various reasons, the results from the test with damaged vapor barriers dealt with in this article focus on the moisture conditions at the wind barrier. Firstly, if there was any effect of the holes made in the vapor barrier, it should be detectable at the wind barrier. Secondly, moisture-related damages were more critical behind the wind barrier than in the cladding, which could easily be changed if damaged.

The results of moisture measurement were expressed as percent by weight (weight %), referring to the moisture content in the dowels. Thereby it was possible directly to see whether the critical level of 20% by weight for mold attack



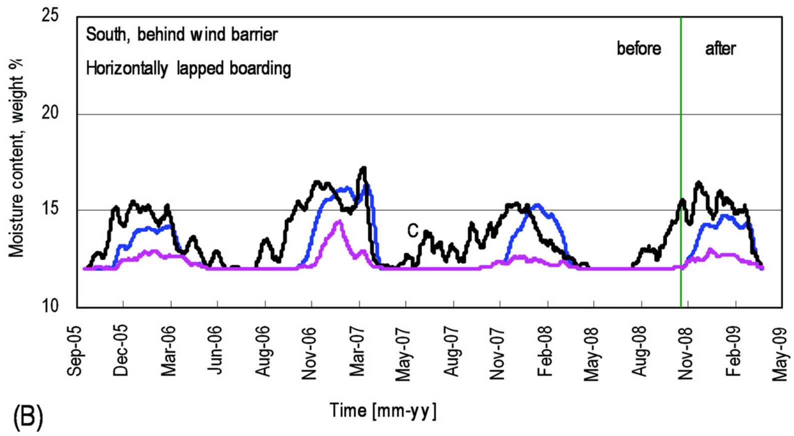




***Figure 7*** *Moisture content (weight %) behind the wind barrier. Façade elements facing (A) north and (B) south. Horizontally lapped boarding. Ventilated cavity (cavity depth: 25 mm, element 1, black), nonventilated cavity (cavity depth: 12 mm, element 4, violet), no cavity (element 11, blue). "Before" and "after" refer to the time when holes were made in the vapor barrier.*

was reached. All curves are moving averages over 15 days of measurements.

### Damaged or Imperfect Vapor Barrier

The moisture content behind the wind barrier before and after the holes were made in the vapor barrier is shown in Figure 7 and 8. Element 11 (Figure 7) was in principle without a cavity, but because of the type of cladding (horizontally lapped boarding, see Figure 5A) there were small, isolated cavities between the wind barrier and the cladding. Element 10 (Figure 8) was partly ventilated. At the bottom was a 5 mm ventilation opening in the 12 mm deep cavity. In element 13, the type of cladding (vertical weatherboard) left no cavity at all (Figure 8). Element 13 had an intact vapor barrier.

### Inspection of the Wind Barrier from the Inside

Figures 9 and 11 show the wind barrier at elements 14 and 8 after removing the inner cladding, vapor barrier, and thermal insulation. Both are designed as shown in Figure 1A, except that element 14 has no cavity. The moisture content in these elements is shown in Figure 10 and 12.

## DISCUSSION

None of the cases where holes were made in the vapor barrier showed a provable effect on the moisture content in the elements (Figures 7 and 8). This indicated that the moisture condition at the wind barrier was only slightly affected by damage to the vapor barrier (at least damage similar to that inflicted in this study). Damage that enables convection through the elements would probably have a more pronounced effect. In that case, one could question whether elements should include a ventilated cavity. Further studies are needed to explore this.

In general, inspection of elements with an intact vapor barrier showed a moisture content behind or in the wind barrier below the critical level, although the moisture content in the

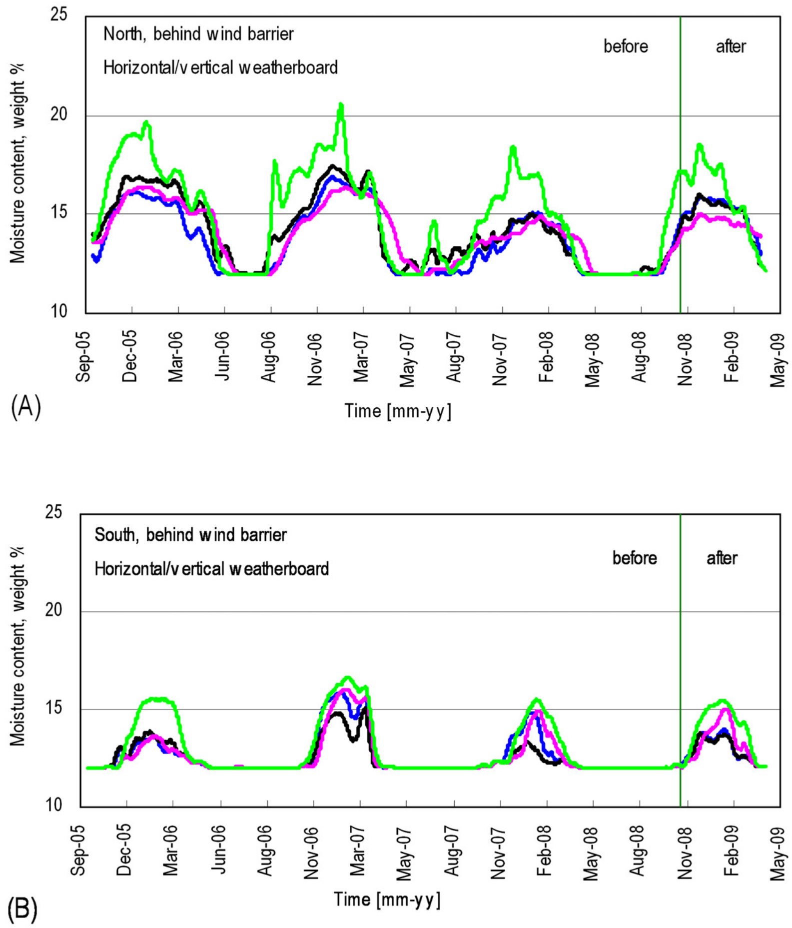



***Figure 8*** *Moisture content (weight %) behind the wind barrier, façade elements facing (A) north and (B) south. Ventilated cavity (element 2, black), nonventilated cavity (element 6, violet), partly ventilated cavity (element 10, blue), no cavity (element 13, green). Horizontal weatherboard (elements 2, 6, and 10; cavity depth: 12 mm) and vertical weatherboard (element 13) as cladding. "Before" and "after" refer to the time when holes were made in the vapor barrier (not element 13).*

***Figure 9*** *Inner side of the wind barrier after four years of exposure: element 14, facing north (vertical weatherboard, no cavity, wind barrier: asphalt-impregnated wood fiberboard).*

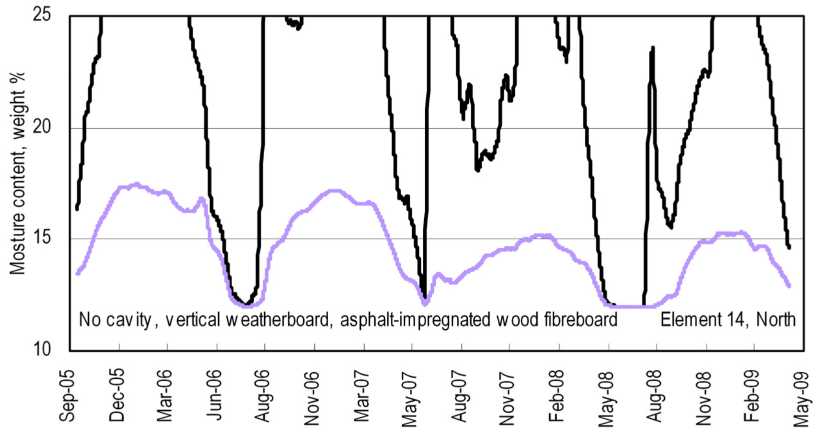



***Figure 10*** *Moisture content (weight %) in element 14, facing north, in the cladding (black), and behind the wind barrier (violet).*

(A)  (B)

***Figure 11*** *Element 8 facing north (horizontal weatherboard, nonventilated cavity, oriented strand board as wind barrier). (A) Wet part of the wind barrier seen from inside and (B) display on the handheld moisture meter indicating critical moisture content (i.e., all indicator lamps are on, including the red ones).*

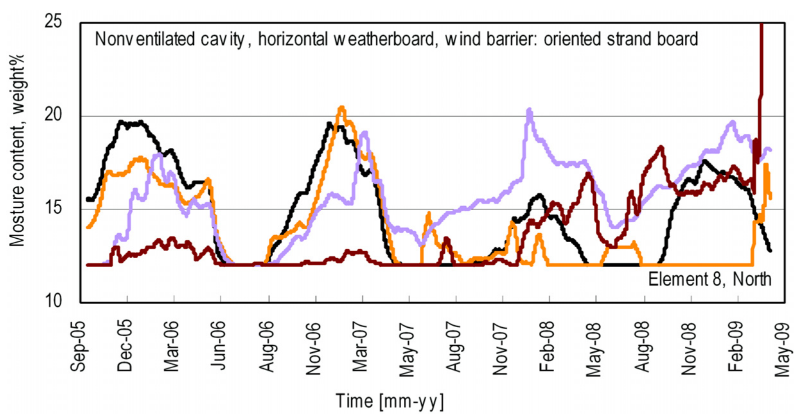



***Figure 12*** *Moisture content (weight %) in element 8 facing north. Moisture content in cladding (black), in the cavity (orange), behind the wind barrier (violet), and in the timber studs (brown). Note the sharp increase of moisture content in the timber studs at the end of the period.*

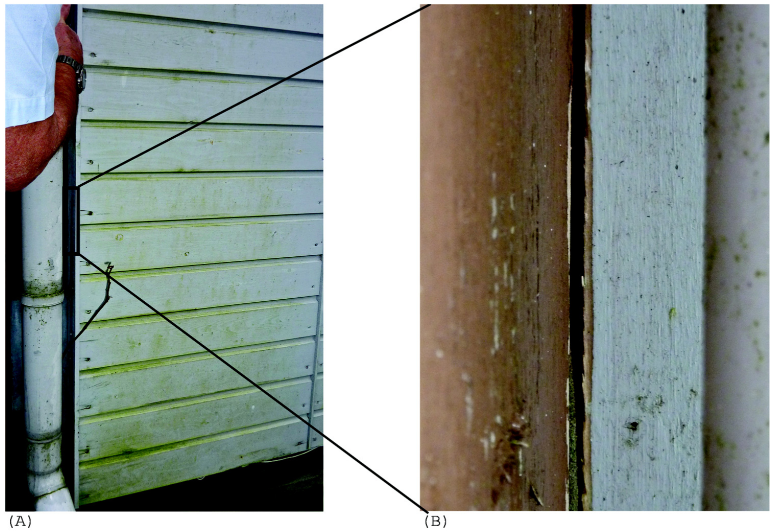



***Figure 13*** *(A) Detail of northeastern corner of the test building with element 8 and its adjacent leaky drainpipe. (B) Close-up of the assembly between the test building and element 8, seen from the side. November 2009 after four years of exposure.*

cladding was sometimes quite high (see Figure 10). In some cases, this might lead to problems (e.g., in combination with freeze/thaw). In element 8, however, the moisture content in the wind barrier and in the timber studs was very high (see Figures 11 and 12). Element 8 was placed at the corner of the test building, and the moisture was explained by poor workmanship on the outer part of the element, which in combination with a leaky drainpipe made it possible for moisture to enter from the side of the element (Figure 13).

Note the amount of algae on the cladding and compare with the condition five months earlier (Figure 14). This is a clear example of how fast the appearance of the surface can change. It also demonstrates how vulnerable this kind of construction is to poor detailing and workmanship, even when the element includes a cavity.

***Figure 14*** *Section of north façade of test building, June 2009. Element 8 is to the left, next to the drainpipe. Algae are not visible on the cladding.*

## FUTURE WORK

The full-scale tests will be continued during 2010 and there are plans to inspect some of the elements when the test building is taken down and moved to a new location, in order to study whether mold growth can be found at the wind barrier, in the cavity, or at the cladding. Furthermore, the inspections will show whether the moisture sensors at the wind barrier, 200 mm from the bottom of the elements, are able to detect the effect of the holes in the vapor barrier, located at different heights in the 2.7 m high elements.

The tests carried out in this study showed that the different types of timber-frame walls in general behaved well when they were exposed to a humid indoor climate (22°C, 60% RH) at the indoor side, although they were vulnerable to defects due to poor workmanship (see Figures 12 and 13). Future work should include exposure of full-scale elements to a typical Danish indoor climate (average values from 40% RH in February to 70% RH in September) as well as exposure of elements with a even less airtight vapor barrier (e.g., larger holes).

Finally, results of the full-scale tests will be compared with computer simulations of the moisture conditions in the elements using MATCH, a one-dimensional method for performing transient calculations of heat and moisture through composite constructions (Pedersen 1990, 1992). The simulations will focus on the conditions at the wind barrier.

## CONCLUSIONS

The full-scale tests indicated that a damaged vapor barrier in elements with a ventilated or a nonventilated cavity did not affect the moisture content at the wind barrier, at least not if the damage consisted of a few large, evenly distributed holes along the centre line of the element. This was probably due to the fact that the remaining part of the vapor barrier was still pretty tight against diffusion and that no convection occurred.

No mold growth or critical moisture content was detected on the inside of a wind barrier after four years of exposure if the vapor barrier was intact and the façade elements were made correctly.

## ACKNOWLEDGEMENTS

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## REFERENCES

Andersen, T., P. Fynholm, M.H. Hansen, and A. Nicolajsen. 2002. *Fugtsikre træfacader: Fugtindhold i højisolerede træfacader* (*Moisture proof wooden facades: Moisture content in highly insulated wooden facades*; in Danish). By og Byg Dokumentation 025. Hørsholm: Danish Building Research Institute.

Brandt, E. and M.H. Hansen. 1999. Measuring moisture content in wood with built in probes—20+ years experience *Proceedings of the 8th International Conference on Durability of Building Materials and Components*, Vancouver, vol. 1:669–79.

de Place Hansen, E.J. and E. Brandt. 2009. The influence of ventilation on moisture conditions in facades with wooden cladding. *Proceedings of the 4th International Building Physics Conference: Energy Efficiency and New Approaches*, Istanbul, pp. 347–54.

Geving, S., T.H. Erichsen, K. Nore, and B. Time. 2006. *Hygrothermal conditions in wooden claddings—Test house measurements*. Project Report 407. Oslo: Norwegian Building Research Institute.

Hansen, M.H., A. Nicolajsen, and B.D. Stang. 2002. On the influence of cavity ventilation on moisture content in timber frame walls. *Proceedings of the 6th Symposium on Building Physics in the Nordic Countries*, Trondheim, Norway, vol. 2:603–10.

Kvande, T., K.R. Lisø, and B. Time. 2007. *Luftede ledninger. Klimapåkjenninger, erfaringer og anbefalinger* (*Ventilated claddings: Climate exposure, experiences and recommendations*; in Norwegian). Rapport 2. Oslo: SINTEF Byggforsk.

NT Build 420. 1993. *Building materials, wood: Moisture content*. Espoo, Finland: NORDTEST.

Pedersen, C.R. 1990. *Combined heat and moisture transfer in building constructions*. PhD thesis. Lyngby: Technical University of Denmark, Thermal Insulation Laboratory, Report No. 214.

Pedersen, C.R. 1992. Prediction of moisture transfer in building constructions. *Building and Environment* 27(3):387–97.

Stang, B.D., A. Nicolajsen, and M.H. Hansen. 2002. Moisture in combined concrete timber-frame walls without vapour barrier. *Proceedings of the 6th Symposium on Building Physics in the Nordic Countries*, Trondheim, Norway, vol. 1:175–82.

TenWolde, A., C. Carll, and V. Malinauskas. 1995. Airflows and moisture conditions in walls of manufactured homes. In *Airflow Performance of Building Envelopes, Components and Systems*, pp. 137–55, M.P. Modera and A.K. Persily, eds. ASTM STP 125. Philadelphia: American Society for Testing and Materials.