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Hansen, Ernst Jan de Place; Brandt, Erik

Published in:
Proceedings of the Fourth International Building Physics Conference: Energy efficiency and new approaches

Publication date:
2009

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

The influence of ventilation on moisture conditions in facades with wooden cladding

E.J. de Place Hansen & E. Brandt
Danish Building Research Institute, Hørsholm, Denmark

ABSTRACT: A ventilated cavity behind the cladding of timber frame walls is often considered good building practice that facilitates the removal of moisture from the construction. However, moisture will only be removed from the construction by ventilating it with dry air, whereas ventilating with humid air might add moisture to the construction.

Full-size wall elements with wooden cladding placed in a test building were exposed to natural climate on the outside and to a humid indoor climate on the inside. Temperature and moisture conditions inside the wall elements and climate parameters were monitored. Test parameters included cavity/unventilated cavity/no cavity, cavity size, vent geometry, type of cladding and type of wind barrier.

The potential durability of the wooden façade claddings was evaluated by coupling the measured time series of moisture content, temperature and time by means of a model for mould growth on wood-based materials.

The paper presents results from the investigation with emphasis on a discussion of the effect of cavity ventilation on moisture content in timber frame walls. In terms of moisture content behind the wind barrier, the behaviour of wood frame walls with a non-ventilated cavity was found not to be inferior to the behaviour of wood frame walls with a ventilated cavity.

1 INTRODUCTION

A ventilated cavity behind the cladding in timber frame walls is often considered a good building practice that facilitates the removal of moisture from the construction. The functions of the cavity are multiple. First of all the ventilation of the cavity removes moisture which by diffusion penetrates through the construction from the interior of the building. Ventilation of the cavity also removes moisture from the cladding itself. Furthermore, a cavity acts as a capillary barrier. A ventilated cavity also implies pressure equalisation across the cladding that acts as a rain screen. Further, any rain that might penetrate into the cavity is removed by gravity drainage of the water to the bottom of the cavity where it can be drained out through the ventilation openings in the cladding.

However, moisture will only be removed from the construction by ventilating it with dry air, i.e. air with lower moisture content than that corresponding to equilibrium with the materials present in the cavity. Ventilation with humid air might add moisture to the construction. TenWolde et al. (1995) found that cavity ventilation was not always successful in providing dry ventilation.

Stovall & Karagiozis (2004) found no significant effect of the cavity depth, comparing 19 mm with 50 mm depth; instead the height of the ventilation opening was found to be the controlling factor. Internal studies at the Danish Building Research Institute (SBi) have similarly shown that the decisive factor for the ventilation capacity of roofs is the size of the ventilation openings to the outdoor air rather than the depth of the ventilation cavity.

Geving et al. (2006) concluded that in general ventilation openings in the top and bottom part of the cladding equivalent to a 4 mm continuous ventilation opening are satisfactory. They also concluded that non-ventilated cavities may behave better than ventilated cavities in facades with only a small amount of driving rain. On the other hand ventilated cavities are still recommended as the best solution in Norway (Kvande et al. 2007).

A previous study carried out at SBi contained full-scale tests with wall elements with wooden claddings and a 25 mm cavity depth. It was concluded that 285 mm thermal insulation, which would satisfy the increased demands to the thermal performance of façade elements, would not give rise to problematic moisture conditions in the construction (Andersen et al. 2002, Hansen et al. 2002, Stang et al. 2002). The study indicated that the cavity behind the wooden cladding may be left out when mounting a vapour barrier at the warm side; however this was based on the result from only one element. Therefore a new set of elements were prepared to further investigate the importance of the ventilation openings.

This paper presents results from the new set of full-scale tests and their bearing on the effect of cavity ventilation on moisture content in timber frame walls. The potential durability of the wooden façade claddings was evaluated by coupling the measured time series of moisture content, temperature and time by means of a mathematical model for the simulation of mould growth on wooden materials.

The model presented by Hukka & Viitanen (1999) was used. It operates with a mould growth index ranging from 0 to 6, where 0 equals no growth and 6 equals a visually detected coverage of 100 %. The model is based on the assumption that the favourable temperature for mould growth is between 0 and 50 ºC and that mould grow beyond this range can not take place. This is a somewhat simplified model, as the shift from favourable to unfavourable conditions can obviously not be as abrupt as the model suggests. On the other hand, the model is sufficient for comparing the behaviour of different elements like in this study.

2 EXPERIMENTAL

Full-size 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. Temperature and moisture conditions inside the wall elements and the relevant climate parameters were recorded.

Test specimens were 18 different wall elements with 285 mm mineral wool thermal insulation (normally 190+95 mm or 240+45 mm). The test parameters included ventilated cavity/non-ventilated cavity/no cavity behind the cladding, type of wind barrier and type of cladding, cf. Table 1.

Apart from elements 15, 16 and 17 all elements had a 0.15 mm polyethylene vapour barrier with a nominal water vapour resistance of 375 GPa m^2 s/kg (or 0.046 perm) and 13 mm gypsum boards as inner cladding. The vapour barrier is placed at the outer side of the inner insulation layer (45 or 95 mm thick). Elements 15 and 16 had a 100 mm lightweight aggregate concrete (LWAC) on the inside. The density of the LWAC was 1200 kg/m^3. After casting, the LWAC elements were kept sealed with plastic until they were mounted in the test house. Element no. 17 had a wooden cassette on the inside and no vapour barrier.

Table 1 and 2 give further information on the construction details of the elements and the applied materials. Element 1 is used as a reference to a previous study (Hansen et al. 2002), where the cavity depth was 25 mm. Figure 1 shows plane sections of the tested wall elements.

Table 1. Construction details of the elements

Element	Cladding[1]	Cavity type[3]	Cavity size mm	Wind barrier size mm	Wind barrier material	moisture capacity
1	horizontally lapped boarding[1]	V	25	9	gypsum board	low
2	horizontal weatherboard[2]	V	12	9	gypsum board	low
3	vertical weatherboard[2]	V	9.5	9	gypsum board	low
4	horizontally lapped boarding[1]	NV	12	9	gypsum board	low
5	vertical board on board[1]	NV	12	9	gypsum board	low
6	horizontal weatherboard[2]	NV	12	9	gypsum board	low
7	horizontal weatherboard[2]	NV	12	12	plywood	high
8	horizontal weatherboard[2]	NV	12	18	OSB/3[5]	high
9	horizontal weatherboard[2]	NV	12	8	cement-bonded particle board	low
10	horizontal weatherboard[2]	"NV"[4]	12	9	gypsum board	low
11	horizontally lapped boarding[1]	NC	0	9	gypsum board	low
12	vertical board on board[1]	NC	0	9	gypsum board	low
13	vertical weatherboard[2]	NC	0	9	gypsum board	low
14	vertical weatherboard[2]	NC	0	9	asphalt impregnated WFB[6]	high
15	vertical weatherboard[2]	V	12+28	12	gypsum board	low
16	vertical weatherboard[2]	NV	12+28	9	gypsum board	low
17	plaster on mineral wool	NC	0	0	none	low
18	5 mm glass, transparent	V	12	9	gypsum board	low

Notes:
1: 22 mm spruce, planed and painted
2: 22 mm pine with tongue and groove, painted
3: V = ventilated, NV = non ventilated, NC = no cavity
4: This element is partly ventilated. At the bottom there is a 5 mm ventilation opening
5: OSB/3: oriented strand board. The number 3 refers to the quality
6: WFB: wood fibreboard

Table 2. Water vapour diffusion resistance of materials for cladding, wind barriers and mineral wool. Air leakage not taken into account.

Material	Thickness mm	Water vapour diffusion resistance GPa s m²/kg	perm	Source
pine board	19	10	1.7	Andersen et al (1993)
spruce board	19	10	1.7	Andersen et al (1993)
gypsum board	9	0.4	43	manufacturer
plywood	12	4	4.4	manufacturer
OSB/3	12	4	4.4	manufacturer
cement-bonded particle board	8	4	4.4	manufacturer
asphalt impregnated WFB	13	0.7	24.9	manufacturer
polyethylene vapour retarder	0.15	375	0.046	Andersen et al (1993)
mineral wool	285	2.1	8.3	manufacturer
gypsum board (inner cladding)	13	0.5	34.8	manufacturer

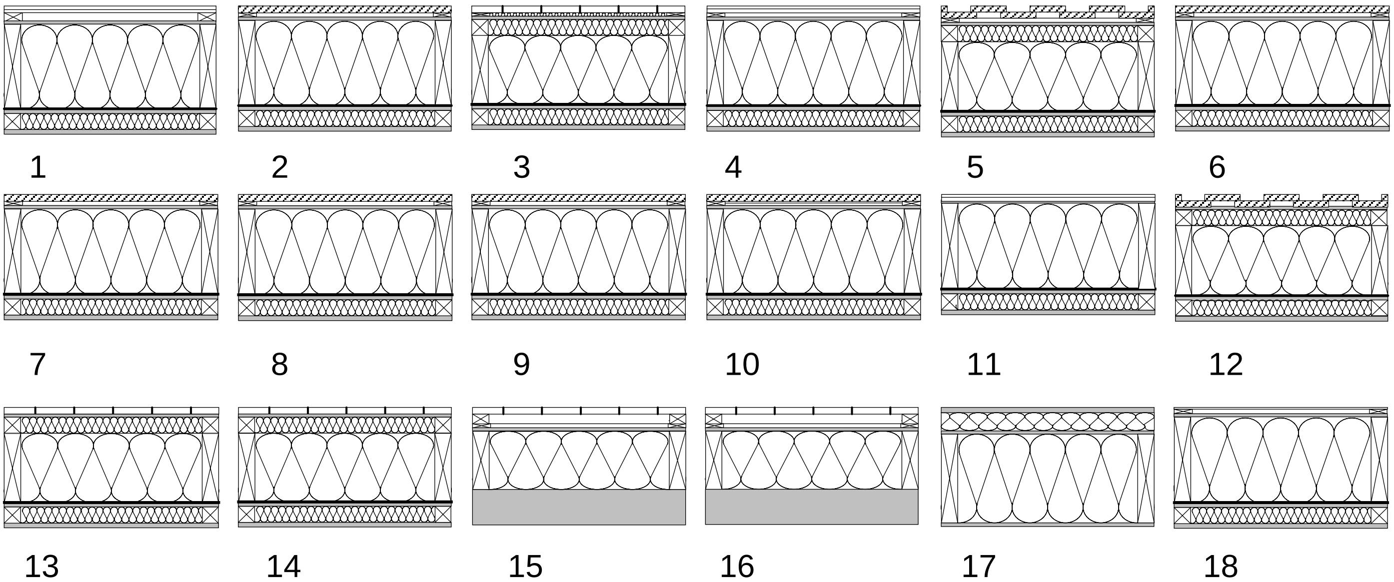

Figure 1. Plane sections of the tested wall elements Outer cladding at the top. Numbers refer to element numbers in Table 1.

The dimension of the wall elements is thickness × 584 × 2683 mm. The thickness is about 350 mm. Two replicates were made of each element. The elements were installed in the south and the north facades in a way that identical elements were tested on both facades of a test building at SBi (Figure 2) measuring 11.5 m by 7.9 m.

The measurements started in September 2005 and the latest data for this study are from May 2008. Temperature and relative humidity is shown in Figures 3 and 4. The indoor climate in the test house was maintained at 22 °C (during winter – no heating or cooling under summer conditions) and 60 % RH. The outdoor temperature varies between -5 ºC and +25 ºC, while the outdoor RH varies between 40 % and 90 % over the year. The first of the three winters recorded was the coldest, cf. Figure 3.

Figure 2. Test building at the Danish Building Research Institute (SBi), seen from the south-east.

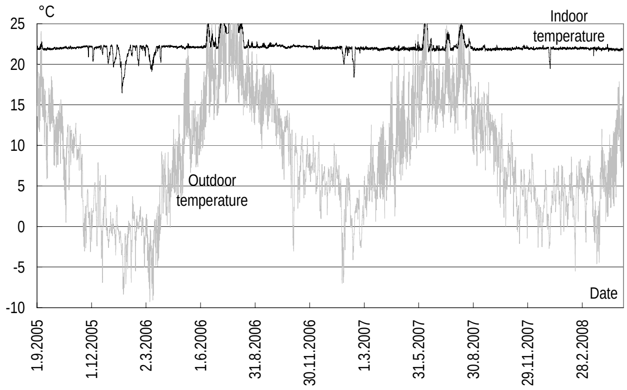

Figure 3. Outdoor and indoor temperatures. September 2005 to May 2008. Outdoor (light grey), indoor (black). Average values based on hourly measurements during 12 hours.

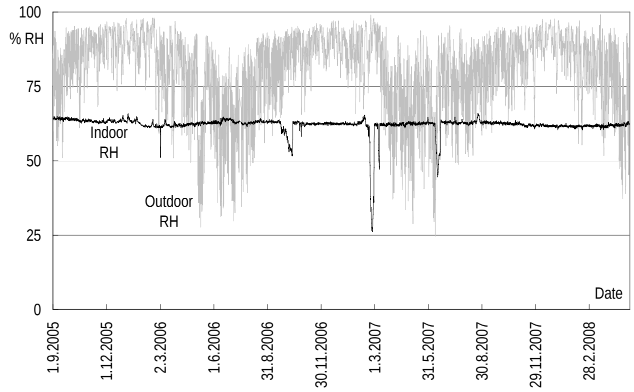

Figure 4. Outdoor and indoor RH. September 2005 to May 2008. Outdoor (light grey) and indoor (black). Average values based on hourly measurements during 12 hours.

3 MEASUREMENTS

Temperature and relative humidity of indoor and outdoor air was recorded every hour. Precipitation was also recorded every hour. Wind speed and wind direction were measured with an ultrasonic anemometer and recorded as 1-hour averages. These were made to supplement recordings of other climate data in order to allow for calculations of hygrothermal conditions by means of MATCH (Pedersen 1992) reported in a following paper.

Moisture content was measured with moisture measuring dowels according to NT Build 420 (1993). Moisture measuring dowels were Ø10 mm beech wood dowels with two electrodes embedded (Brandt & Hansen 1999). The electrical resistance between the electrodes was measured, adjusted for temperature and converted to wood moisture content. The electrical resistance becomes very high when the wood becomes dry; hence the lower limit of moisture content measurement was in the order 11 weight % with the applied data logger.

The moisture measuring dowels were used to measure the moisture content in the studs, in the distance battens between cladding and wind barrier, in the wooden claddings, in the cavity, and in the thermal insulation adjacent to the wind barrier. 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.

4 RESULTS

Results from the full-scale exposure are shown in the following as results from the measurement of moisture content, and results from the calculation of mould growth.

4.1 *Moisture content*

The effect of the ventilation conditions on the moisture content behind the wind barrier, when horizontally lapped boarding was used as cladding, is presented in Figures 5 and 6, showing the results at the north side and south side of the test building, respectively. Correspondingly, Figure 7 and 8 show the moisture content in the cladding itself on façade elements facing north and south, respectively.

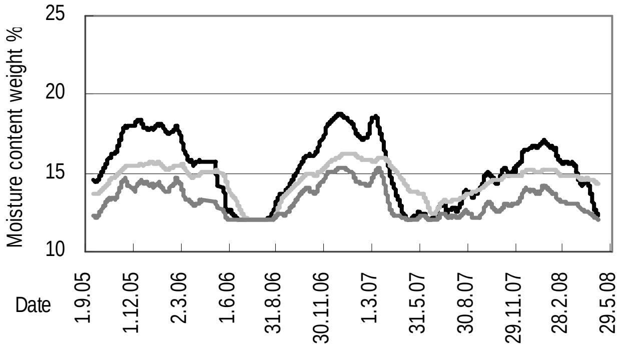

Figure 5. Moisture content (weight %) behind wind barrier in façade elements facing north. Horizontally lapped boarding. Ventilated cavity – depth 25 mm (Element no. 1, light grey), non-ventilated cavity – depth 12 mm (Element no. 4, dark grey), no cavity (Element no. 11, black).

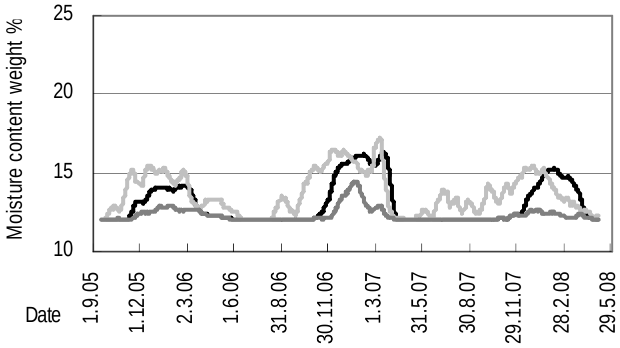

Figure 6. Moisture content (weight %) behind wind barrier in façade elements facing south. Horizontally lapped boarding. Ventilated cavity – depth 25 mm (Element no. 1, light grey), non-ventilated cavity – depth 12 mm (Element no. 4, dark grey), no cavity (Element no. 11, black).

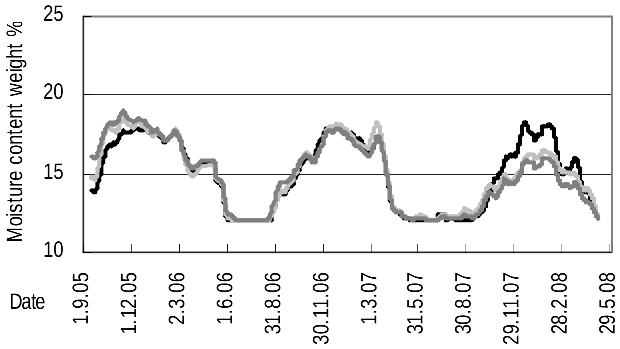

Figure 7. Moisture content (weight %) in the cladding. Façade elements facing north. Horizontally lapped boarding. Ventilated cavity – depth 25 mm (Element no. 1, light grey), non-ventilated cavity – depth 12 mm (Element no. 4, dark grey), no cavity (Element no. 11, black).

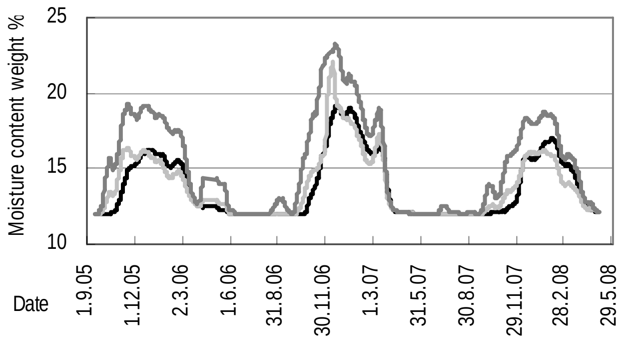

Figure 8. Moisture content (weight %) in the cladding. Façade elements facing south. Horizontally lapped boarding. Ventilated cavity – depth 25 mm (Element no. 1, light grey), non-ventilated cavity – depth 12 mm (Element no. 4, dark grey), no cavity (Element no. 11, black).

The effect of the ventilation conditions on the moisture content in the cladding when horizontal weatherboards was used as cladding is shown in Figures 9 and 10. Figure 11 and 12 show the effect of the type of wind barrier on the moisture content in the cladding with a non-ventilated cavity.

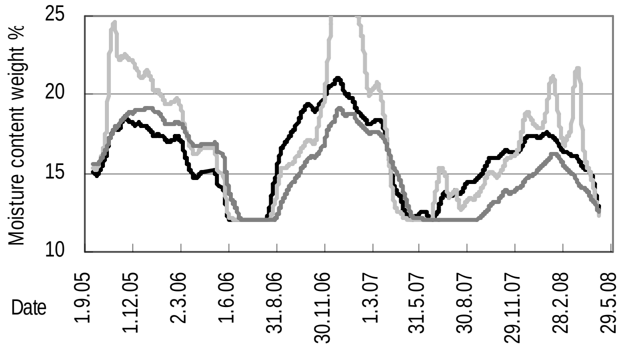

Figure 9. Moisture content (weight %) in the cladding. Façade elements facing north. Horizontal weatherboard. Ventilated cavity – depth 12 mm (Element no. 2, light grey), non-ventilated cavity – depth 12 mm (Element no. 6, dark grey), "no cavity" (Element no. 10, black).

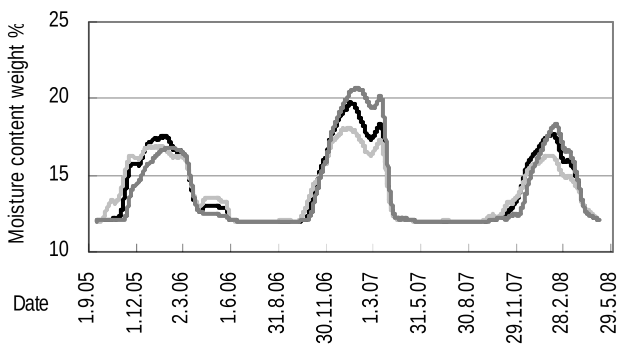

Figure 10. Moisture content (weight %) in the cladding. Façade elements facing south. Horizontal weatherboard. Ventilated cavity – depth 12 mm (Element no. 2, light grey), non-ventilated cavity – depth 12 mm (Element no. 6, dark grey), "no cavity" (Element no. 10, black).

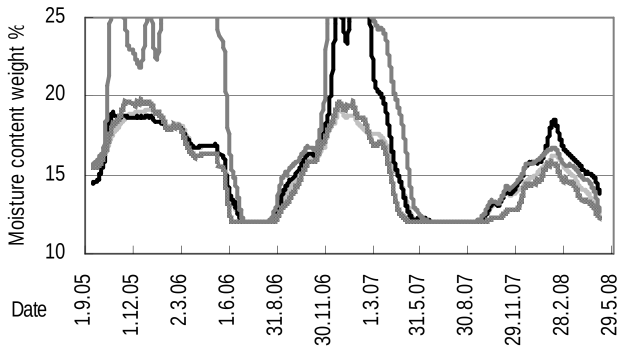

Figure 11. Moisture content (weight %) in the cladding, Façade elements facing north. Horizontal weatherboard. Non-ventilated cavities – depth 12 mm. Wind barrier: Gypsum board (Element no. 6, light grey), plywood (Element no. 7, black), OSB (Element no. 8, dark grey), cement-bonded particle board (Element no. 9, grey).

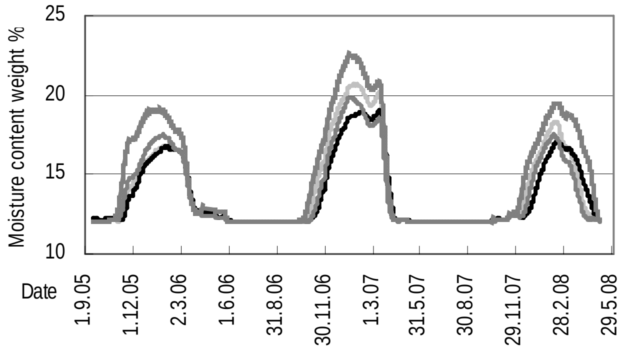

Figure 12. Moisture content (weight %) in the cladding, Façade elements facing south. Horizontal weatherboard. Non-ventilated cavities – depth 12 mm. Wind barrier: Gypsum board (element no. 6, light grey), plywood (element no. 7, black), OSB board (element no. 8, dark grey), cement-bonded particle board (element no. 9, grey).

4.2 *Mould growth*

In Figure 13 and 14 moisture contents are transformed to mould growth indices according to the model of Hukka & Viitanen (1999). Figure 13 relates to Figure 9, and Figure 14 to Figure 11.

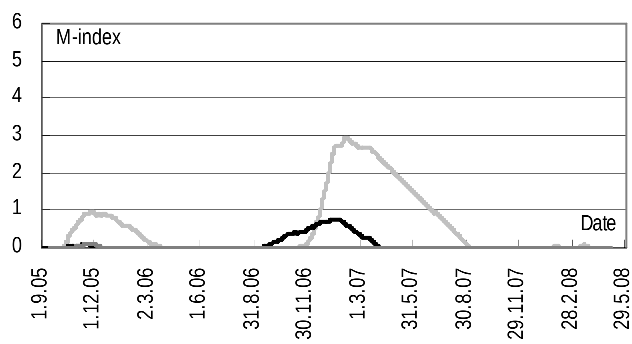

Figure 13. Mould growth index. Cladding of façade elements facing north. Horizontal weatherboard. Ventilated cavity-depth 12 mm (Element no. 2, light grey), non-ventilated cavity - depth 12 mm (Element no. 6, dark grey), "no cavity" (Element no. 10, black). The growth indices are based on the moisture contents in Figure 9.

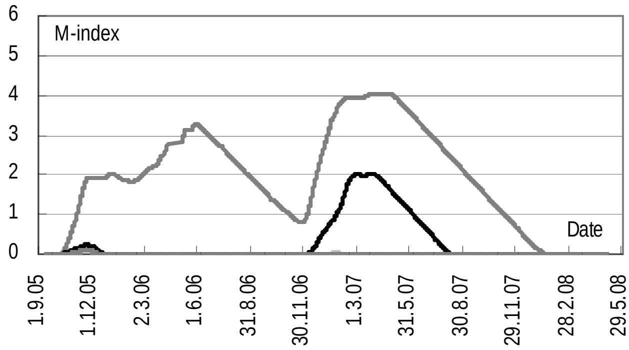

Figure 14. Mould growth index. Cladding of façade elements facing north. Horizontal weatherboard. Non-ventilated cavity. Wind barrier: Gypsum board (Element no. 6, light grey), plywood (Element no. 7, black), OSB (Element no. 8, dark grey), cement-bonded particle board (Element no. 9, grey). The growth indices are based on the moisture contents in Figure 11. Mould index for element 6 and 8 is 0 for almost the whole test period.

5 DISCUSSION

Based on the results presented in Figures 5-14 and corresponding results for the other elements, the effects of cavity ventilation on moisture content and mould growth in timber frame walls is evaluated and discussed in the following.

5.1 *Moisture content*

The moisture content behind the wind barrier shows that the element with a non-ventilated cavity behaves best in elements facing north as well as in elements facing south when using horizontally lapped boarding as cladding (Figures 5 and 6). This is not the case when comparing the moisture contents in the cladding (Figures 7 and 8). In the elements facing south the moisture content is highest in the element with a non-ventilated cavity (Figure 8), while the moisture content in the cladding of elements facing north can be considered almost independent on the type of cavity (Figure 7).

Quite opposed to this result the type of cavity has a marked effect on the moisture content in the cladding of elements facing north when using horizontal weatherboards (Figure 9) with the element with a ventilated cavity behaving worst, while the effect is much smaller and with another ranking in the elements facing south (Figure 10).

Also the effect of the type of cladding on the level of moisture content in the cladding is dependent on the orientation of the elements (Figures 7–10).

A gypsum board which is used as a reference in this study is a much better choice as wind barrier than plywood or cement-bonded particle board in elements facing north (Figure 11). The effect is much smaller in the elements facing south (not shown).

Table 3 gives an overview of the evaluations of how moisture content in the wall elements and the type of cavity affect each other. The wall elements are organised after the type of cladding. All the elements mentioned in Table 3 have the same wind barrier. In some cases the ranking of the different kinds of cavity, wind barriers etc. changes during the test period, thus indicating that some elements are reacting more slowly – maybe due to smaller capability of removing moisture from the construction – to the climate than others.

An example is shown in Figure 9 where the element with a non-ventilated cavity has higher moisture content than a corresponding element with a partly ventilated cavity the first winter but lower moisture content the following winters. The results in Figure 7 suggest that the time has a positive effect on the moisture content in the cases with a cavity but not in the case without cavity. Both Figure 7 and 9 refer to the conditions in the cladding.

Behind the wind barrier of the north façade, the best conditions were achieved with a non-ventilated cavity and the worst with no cavity (e.g. Figure 5). Cases with vertical weatherboard and LWAC on the inside are the exception.

Behind the wind barrier of the façade facing south, the most favourable moisture conditions were reached with a non-ventilated cavity (e.g. Figure 6).

In the cladding of the façade facing north, a non-ventilated cavity appears to be best, except for the element with vertical weatherboard and LWAC on the inside (these elements are without vapour barrier).

Table 3. Effect of ventilation conditions on the moisture content when using gypsum board as wind barrier. Evaluation of results.

Cladding	Behind wind barrier		In the cladding	
	North	South	North	South
Horizontally lapped boarding(1,4,11)	NV-V-NC	NV-NC-V	[NV-V]-NC	[NC-V]-NV
Horizontal weatherboard (2,6,10)	[V-NV-"NV"]	[V-NV-"NV"]	NV-"NV"-V	V-{NV-"NV"}
Vertical weatherboard (3,13)	[V-NC]	[V-NC]	*	[NC-V]
Vertical board on board (5,12)	NV-NC	NV-NC	NV-NC	NV-NC
Vertical weatherboard with a LWAC back wall and no vapour barrier (15,16)	V-NV	NV-V	V-NV	V-NV

Note: NV, V and NC refer to the cavity (cf. Table 1). [ ] indicates equal development of the moisture content. { } indicates different progress of the moisture content but equal average level. * indicates that evaluation is not possible because of missing or wrong data.

Table 4. Effect of ventilation conditions on the mould growth index. Evaluation of results.

Cladding	In the cladding	
	North	South
Horizontally. lapped boarding(1,11)	[NV-V-NC]0	[V-NC]0-NV1
Horizontal weatherboard (2,6,10)	NV0-"NV"1-V3	[V-NV-"NV"]0
Vertical weatherboard (3,13)	NC6	NC0-V3
Vertical board on board (5,12)	[NV-NC]0	NV0-NC1
Vertical weatherboard with a LWAC back wall and no vapour barrier (15,16)	V3-NV6	[NV-V]0

Note: NV, V and NC refer to the cavity (cf. Table 1). [ ] indicates equal development of the moisture content. { } indicates different progress of the moisture content but equal average level. * indicates that evaluation is not possible due to lacking or wrong data. Numbers indicate the level of mould growth index on a scale from 0 (no growth) to 6.

In the cladding of the facade facing south, a ventilated cavity appears in general to be best. No cavity leads to the highest moisture content.

Overall, it appears that elements with no cavity have the highest moisture content. Facade elements with a non-ventilated cavity behave in many cases better than corresponding elements with a ventilated cavity.

On the other hand, in the case of non-ventilated cavities it takes a couple of years for the moisture content behind the wind barrier or in the cladding (Figure 11) to reach an acceptable level, depending on the type of wind barrier. After a couple of years dependency on the wind barrier almost vanishes.

The results presented in this study are in accordance with previous referred studies (Stovall & Karagiozis 2004; Geving et al 2006); e.g. showing that elements with non-ventilated cavities in some cases behaves better than elements with ventilated cavities and that the depth of the cavity has no effect on the moisture content.

5.2 *Mould growth*

Table 4 gives an overview of the evaluation of mould growth indices in the cladding. Behind the wind barrier the index is always lower than 0.5, i.e. no mould growth.

In the cladding of the north façade a non-ventilated cavity is best except when vertical weatherboard has LWAC on the inside. In this case a ventilated cavity is best. In general, elements with vertical weatherboards as cladding give a high index for the north facade. There is no clear picture for the south façade.

Comparing Figure 11 and Figure 14 indicates that although the moisture content in the cladding decreases each summer, it takes time for the mould growth index to decrease as well. This of course can not be correct, since the index should be 0 when the moisture content is below 17 weight % or 80 % RH. The explanation to this surprising observation is not found yet.

The results from the test building are to be calibrated with MATCH, a 1-dimensional method for performing transient calculations of heat, liquid and vapour moisture (Pedersen, 1990, 1992). Then further MATCH simulations will be made for façade elements not included in the full-scale tests. These results will be reported in a future paper. Also, a new set of measurements are planned, where holes are made in the vapour barrier of some of the elements reflecting the fact that quite often the vapour barrier is damaged when mounted. At the same time elements will be inspected in order to calibrate the calculations of the mould growth index.

6 CONCLUSION

The results of the tests performed so far suggest that wooden façades with a cavity behind the cladding perform well independent of whether the cavity is ventilated or not. However, if non-ventilated cavities are used the type of wind barrier is important.

Façade elements without a cavity should be avoided, as they give rise to moisture content higher than recommended in terms of potential mould growth.

REFERENCES

Andersen, N.E.; Christensen, G.; and Nielsen, F. 1993. *Bygningers fugtisolering* (in Danish: Moisture proofing of buildings), SBI-anvisning 178, Danish Building Research Institute, Hørsholm.

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

Brandt, E., & Hansen, M.H. 1999. Measuring moisture content in wood with built in probes - 20+ years experience, *Proc. 8th International Conference on Durability of Building Materials and Components, Vancouver, Canada, May 30-June 3 1999*, vol. 1, pp. 669-679.

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

Hansen, M.H., Nicolajsen, A. & Stang, B.D. 2002. On the influence of cavity ventilation on moisture content in timber frame walls, *Proc. 6th Symposium on Building Physics in* *the Nordic Countries, Trondheim, Norway, 17-19 June 2002*, vol. 2, pp. 603-610.

Hukka, A. & Viitanen, H.A. 1999. A mathematical model of mould growth on wooden material. *Wood Science and Technology*, vol.33, pp.475-485.

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

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

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

Pedersen C.R. 1992. Prediction of moisture transfer in building constructions. *Building and Environment*, vol.27, no.3, pp.387-397.

Stang, B.D, Nicolajsen, A. & Hansen, M.H. 2002, Moisture in combined concrete timber-frame walls without vapour barrier. *Proc. 6th Symposium on Building Physics in the Nordic Countries, Trondheim, Norway, 17-19 June 2002*, vol. 1, pp. 175-182.

Stovall, T.K. & Karagiozis, A. 2004. Airflow in the ventilation space behind a rain screen wall. *Proc. Performance of Exterior Envelopes of Whole Buildings IX International Conference*, Clearwater Beach, Florida, U.S.A, 5-10 December 2004, ASHRAE.

TenWolde, A., Carll, C. and Malinauskas, V. 1995. Airflows and moisture conditions in walls of manufactured homes, in: *Airflow performance of building envelopes, components and systems*, eds M.P. Modera & A.K. Persily, ASTM STP 125, American Society for Testing and Materials, Philadelphia, pp. 137-155.