Thermal transmittance of reed-insulated walls in a purpose-built test house

M. Miljan, M.-J. Miljan, J. Miljan, K. Akermann and K. Karja

Department of Rural Building, Estonian University of Life Sciences, Tartu, Estonia

SUMMARY

We studied the construction and thermal properties of walls insulated with reed, to enable comparisons with other wall structures that are widely used in building. In 2010 we built a test house insulated with reed adjacent to the Estonian University of Life Sciences in Tartu. The load-bearing structure of the house was a timber frame, and four different technologies were used to place reed insulation in its external walls. The thickness of the reed layer was 450 mm in all cases, and both sides (inside and outside) of the walls were rendered with clay plaster. Records were kept of time spent and materials used in construction of the different types of walls, and these data were used to calculate unit (m^{-2}) requirements of time and materials for each wall type to enable direct comparisons. From October 2010 to March 2012, heat flow plates were used to measure the thermal transmittance of the walls of the completed house and the results were compared with the thermal transmittance requirements set by Estonian legislation. Only one of the test walls met the Estonian standard. This was insulated with compressed loose reed, placed horizontally in the wall.

KEY WORDS: clay plaster; installation technology; material consumption; natural insulation material

INTRODUCTION

There are 27,746 hectares of *Phragmites australis* reedbed in Estonia (Kask & Kask 2008). Reed is a natural and renewable construction material that has been used for centuries as roofing and, to a lesser degree, for wall insulation and lathing. In 2010, the thermal conductivity (λ) of chopped locally harvested reed (bulk density 76 kg m^{-3}) was measured in laboratory tests carried out at the Department of Rural Building of the Estonian University of Life Sciences (Miljan & Miljan 2012b). The value obtained (0.076 W m^{-1} K^{-1}) was similar to a value (0.08 W m^{-1} K^{-1}) reported for reed at bulk density 76.5 kg m^{-3} by Veljeliene *et al* (2011), and stimulated our interest in determining the thermal transmittance of walls insulated with reed. Further tests were performed in 2009–2011 on two reed wall panels that were constructed in window openings in the laboratory of the Department of Rural Building in Tartu and covered on both sides (inside and outside) with 50 mm thick layers of clay plaster. The thermal transmittance (*U* value) of the panel with horizontally laid reed was 0.145 W m^{-2} K^{-1}, and that of the panel insulated with 48 cm thick reed blocks was 0.148 W m^{-2} K^{-1} (Miljan & Miljan 2012b). Thus, the performance of both panels was well within the requirement set by the Estonian standard ($U < 0.2$–0.25 W m^{-2} K^{-1}).

In order to move closer to a real-life scenario, we needed to study the thermal transmittance of whole external walls insulated with reed. Here we report on the construction of a test house, and the results of two studies whose objectives were to:

1) calculate the time and materials required to build external reed walls with different structures; and
2) measure the thermal transmittance of these walls.

METHODS

Construction of the test house

The test house was built in autumn 2010 on a sloping site in the primaeval valley of the Emajõgi River behind the Institute of Forestry and Rural Building. It was designed to a specification provided by the Department of Rural Building, and staff and students participated in its construction. The plan and cross-section of the building are shown in Figure 1. The plan dimensions are 4,060 × 6,060 m. All of the external walls are finished on both sides with clay plaster, but they have different structures, which are described below.

Wall VS1

The bearing structure is a framework of vertical timber posts (50 × 100 mm) at 1600 mm spacing, with 20 × 100 mm timber boards fixed horizontally

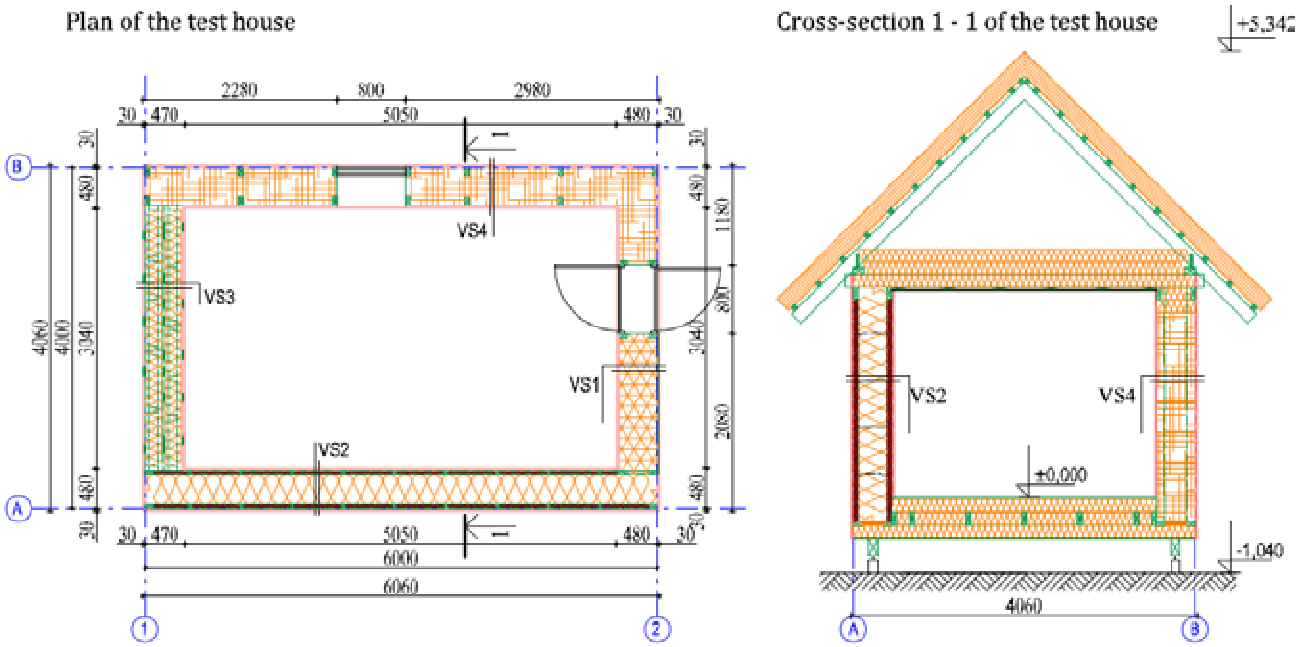


Figure 1. Plan and cross-section of test house with reed-insulated walls. See Figure 2 for structural details of the different wall types (VS1, VS2, VS3 and VS4).

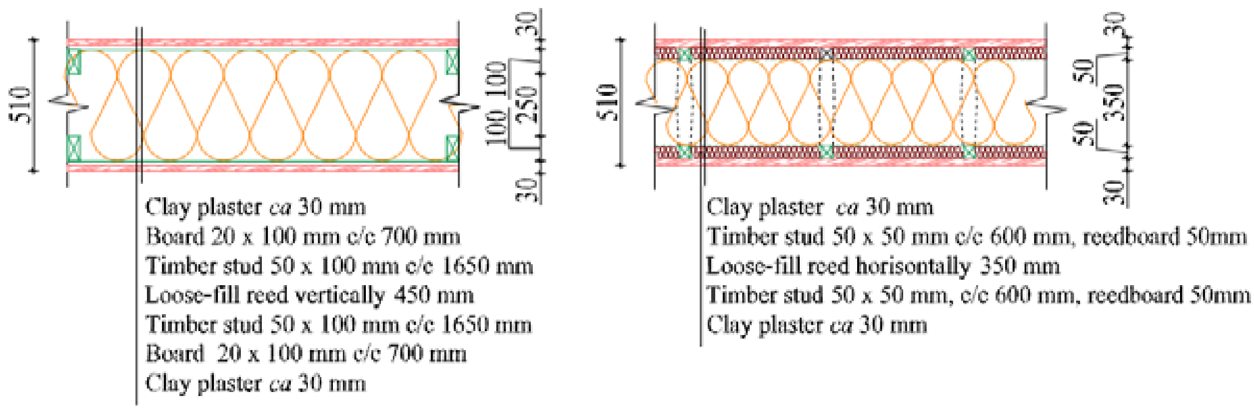
between them at 700 mm spacing (Figures 2a, 3). The insulation is loose reed placed vertically between the boards, bundled together with securing straps and fixed with plastic strings pulled through the reed. The filling is as dense and even as possible to maximise thermal resistance.

Wall VS2

The bearing structure is made from 50 × 50 mm timber posts at 600 mm spacing, and the insulation is a 350 mm thick layer of loose reed which was laid horizontally inside the frame and packed as densely and evenly as possible (Figures 2b, 3). On the outside and inside faces of the wall, 50 mm thick pre-cut reed boards similar to the reed panels described by Köbbing *et al*. (2013) (see Figure 4) were attached longitudinally to fill the recesses between the frame posts.

Wall VS3

This wall is a two-layered reed panel wall, constructed from four reed panels which were manufactured at the building site (Figure 5). The panels have timber frames, all 2,800 mm high,



a) VS1: wall with vertically laid reed. *b) VS2: wall with horizontally laid reed.*

Figure 2. Drawings showing the structure of wall types VS1 and VS2 in cross-section.

Figure 3. Photographs of two walls of the test house during construction. Above: wall type VS1 (with reed laid vertically); below: wall type VS2 (with reed laid horizontally).

Figure 4. Above: machine from China for making reed boards; below: machine for making Berger boards. Reed boards 50 mm thick, cut to size, were used to fill the recesses between the (50 × 50 mm) supporting timbers of wall type VS2, both inside and outside, thus creating relatively flat surfaces for plastering.

Figure 5. Stages in the manufacture of reed panels for Wall VS3. The timber frame was filled with loose reed by placing the stems horizontally, compressing and tying them to the frame posts (left), then trimming with a chainsaw (right).

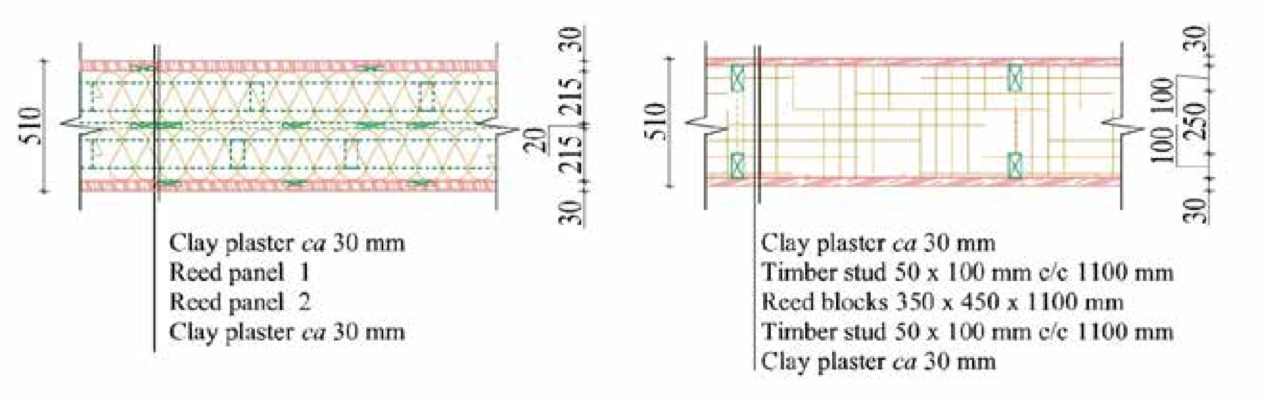
but one of each pair is 1,400 mm wide and the other 1,600 mm wide. Each panel is filled with loose reed laid horizontally and compressed as for wall type VS2, but the layer of reed insulation is only 215 mm thick and it is contained between (vertical) 20 × 100 mm timber boards. The wall was assembled with one pair of panels standing side by side to form its outside face, layered with the other pair (forming the inside face) (Figures 6a, 7) such that the central joins in the two faces were offset from one another by 200 mm. The (20 mm) gaps between the layered panels were filled with loose reed, and the panels were fixed together with connectors applied to the timber boards.

Wall VS4

This is a reed block wall. The blocks (450 mm thick, 350 mm high and one metre long) were made from cut reed at the reedbed using a tractor-drawn baling machine (instead of bundling). The bearing structure of this wall was made from 50 × 100 mm cross-section timber posts placed 1,100 mm apart. The reed blocks were stacked and tied into the spaces between the timbers, and the gaps between them were packed with loose reed (Figures 6b, 7).

Comparison of time and materials requirements

For each wall type, the number of man hours spent on each phase of construction and the quantities of materials used were recorded to the nearest unit (e.g. m^2 for reed board, kg for clay plaster, number of bundles for loose reed). Because the amounts of timber used were small, these were measured in dm^3 (cubic decimetres) rather than m^3. Wastage was not taken into account. The total time and materials requirements for each wall type were then divided by the area of wall constructed to give a unit value (m^{-2}) that could be compared between types.



a) VS3: reed panel wall. *b) VS4: reed block wall.*

Figure 6. Drawings showing the structure of wall types VS3 and VS4 in cross-section.

Thermal transmittance

The thermal characteristics of the different wall types were studied from 2010 to 2012. The following values were measured (continuously) and recorded at ten-minute intervals:

- q heat flow through wall (W m^{-2});
- T_e outdoor air temperature (°C);
- T_{se} temperature of outer surface of wall (°C);
- T_{si} temperature of inner surface of wall (°C);
- T_i room temperature (°C).

Heat flux was measured with an epoxy resin heat flow plate FQ90119, size 250 × 250 mm, and the data were saved into an Almemo data logger. Temperatures were measured and saved with HOBO U12-011 Temperature/ Relative Humidity Data Loggers.

Thermal transmittance (U) is the rate of transfer of heat through one square metre of wall divided by the difference between the indoor and outdoor temperatures, and was calculated as:

$$\boldsymbol{U} = \frac{\boldsymbol{q}}{\boldsymbol{T_i - T_e}} \qquad [1]$$

Both the temperature measurements and the calculated values of U varied widely during the two-year period of measurements because we were working in a non-steady environment. The closest approach to steady-state conditions was observed during a period of 14 days in February 2012, when the fluctuations were smallest and most uniform. A value of U_d for each wall type was calculated from the data collected during this period as:

$$\boldsymbol{U_d} = \boldsymbol{U_{mean}} + (\boldsymbol{k\,s}) \qquad [2]$$

where:

U_{mean} is the average of all measurements;

s is the standard deviation of the mean; and

k is the Student coefficient (=1)

RESULTS

Quantities of materials used

The total quantities of materials used per wall and per square metre of each wall type are shown in Table 1. The amount of clay plaster required to finish one square metre was roughly the same for all wall types, but slightly less for type VS1 because the timber boards protruded more than in any of the other types so that, to achieve a smooth finish, they received a slightly thinner (10–20 mm) layer of plaster coating than the rest of the walls. Amongst the three wall types that were insulated with loose reed, the smallest number of (21 cm diameter) reed bundles per unit area (14.4 bundles m^{-2}) was required for the vertically laid wall VS1 and the largest number (20.0 bundles m^{-2}) for the horizontally laid panel wall VS3. The panel wall also required the largest unit quantity of timber.

Construction time

Table 2 shows the time spent on each separate activity involved in the construction process for each wall type. The most time-consuming tasks were the construction of panels (VS3), the filling of timber frames with loose reed (VS1 and VS2), and plastering (all wall types). Figure 8 compares the

Figure 7. Photographs of two walls of the test house during construction, before rendering with clay plaster. Above: Wall VS3 (reed panel wall); below: VS4 (reed block wall).

Table 1. Quantities of materials used in construction of the different types of external walls used in the test house, calculated as totals and per square metre for each wall type (after Miljan & Miljan 2012a).

Code for wall type	VS1		VS2		VS3		VS4	
Area of wall (m^2)	5.0		16.8		8.6		18.6	
	total	*m^{-2}*	total	*m^{-2}*	total	*m^{-2}*	total	*m^{-2}*
reed board (m^2)			31	*1.8*				
21 cm* reed bundles (number)	72	*14.4*	270	*16.1*	172	*20.0*		
reed blocks (number)							38	*2.0*
50 × 50 mm timber (dm^3)			140	*8.3*	63	*7.3*		
50 × 100 mm timber (dm^3)	28	*5.6*					196	*10.5*
20 × 100 mm timber (dm^3)	24	*4.8*			112	*13.0*		
total volume of timber (dm^3)	52	*10.4*	140	*8.3*	175	*20.3*	196	*10.5*
clay plaster (kg)	538	*107.6*	2016	*120.0*	1042	*121.2*	2242	*120.5*

*The nominal size (21 cm) of the reed bundles is their diameter (see Köbbing *et al*. 2013, footnote on page 4).

Table 2. Time (in hours) spent on the different activities involved in construction of the four types of reed-insulated wall (after Miljan & Miljan 2012a).

Code for wall type	VS1		VS2		VS3		VS4	
Area of wall (m^2)	5.0		16.8		8.6		18.6	
	total	*$h\ m^{-2}$*	total	*$h\ m^{-2}$*	total	*$h\ m^{-2}$*	total	*$h\ m^{-2}$*
Construction of timber frame	4.0	*0.9*	15.1	*0.9*			16.8	*0.9*
Filling framework with loose reed	12.0	*2.4*	51.0	*3.0*				
Covering walls with reed board			15.0	*0.9*				
Placing of reed blocks							26.0	*1.4*
Construction of reed panels					28.0	*3.3*		
Application of reed panels					12.0	*1.4*		
Preparation for plastering	1.6	*0.3*	6.3	*0.4*	3.2	*0.4*	6.9	*0.4*
Plastering	11.8	*2.4*	44.2	*2.6*	22.8	*2.6*	49.2	*2.6*
Totals	29.4	*5.9*	131.6	*7.8*	66	*7.7*	98.9	*5.3*

total unit construction times (h m^{-2}) for the four wall types tested here and one with a timber framework, glasswool insulation and timber board sidings that was studied by Kukka & Miljan (2009). The unit time required for construction of our test walls ranged from 5.3 to 7.8 h m^{-2}, which was 126–186 % of the unit construction time for the glasswool-insulated wall (4.2 h m^{-2}). In other words, the construction of lightweight walls with reed insulation is generally rather time-consuming. Amongst the reed wall designs that we trialled, construction was fastest for the reed block wall VS4. The longest unit building time (7.8 h m^{-2}) was for wall VS2, which was insulated with horizontally laid loose-fill reed. Wall VS3 (the panel wall, which was also insulated with horizontally laid reed) came a close second with a building time of 7.7 h m^{-2}.

Thermal transmittance

Figure 9 shows how the thermal transmittance of the respective external wall types fluctuated during the latter half of February 2012, and values of U_d (Equation 2) calculated from these data are shown in Figure 10. Type VS2 exhibited the lowest thermal transmittance (U_{mean} = 0.130 ± 0.077 W m^{-2} K^{-1}; U_d = 0.207 W m^{-2} K^{-1}), and the highest value was recorded for VS1 (U_{mean} = 0.257 ± 0.126 W m^{-2} K^{-1}; U_d = 0.383 W m^{-2} K^{-1}).

DISCUSSION

Differences between thermal conductivity values provided by the manufacturer and those actually achieved in practice when insulation materials are installed in real walls are highlighted by Domínguez-Muñoz *et al*. (2009). As the reed insulation layer was 450 mm thick in all of the wall types that we tested, the differences in their thermal resistance characteristics can be attributed to the differences in construction technology and, possibly, also to variation in the quality of workmanship as our practical experience in the construction of each type of wall developed. Construction of the wall with reed insulation laid vertically in a timber framework (VS1) was technically the most complicated procedure, and the resulting wall has the highest thermal transmittance of the wall types tested. This may arise from the fact that the vertical gaps between the reed stems

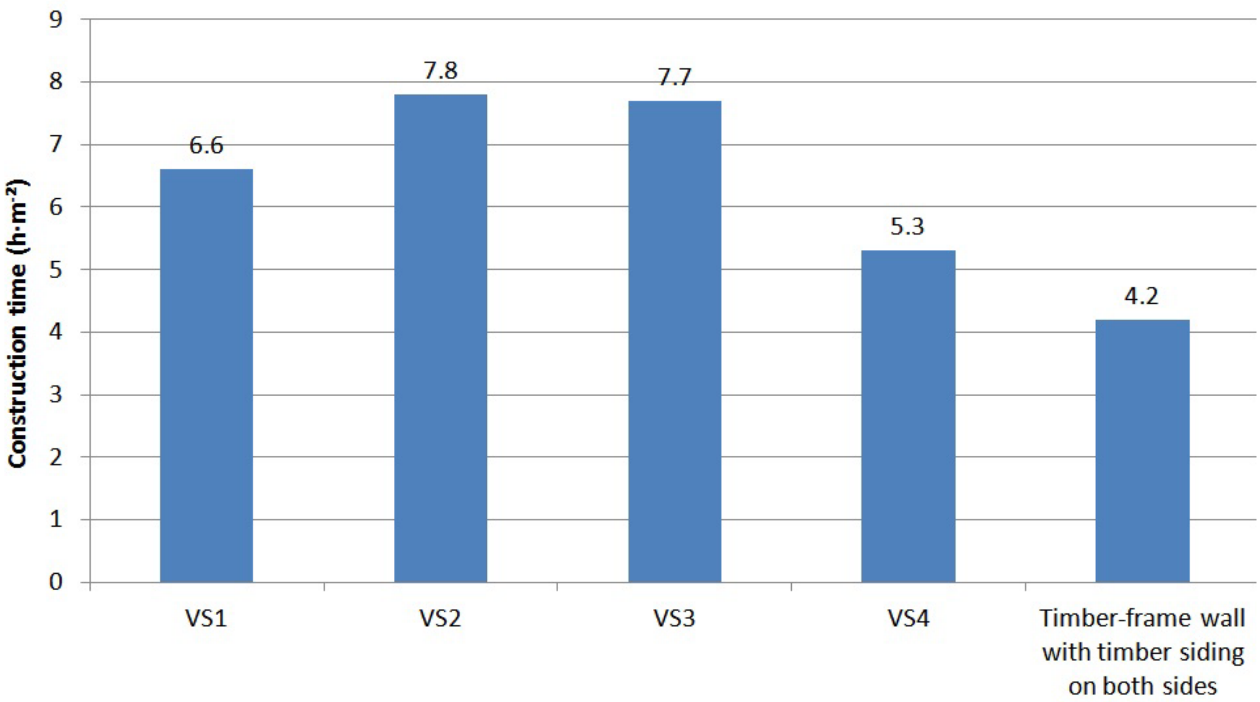


Figure 8. Comparison of unit construction times (h m^{-2}) for the four types (VS1, VS2, VS3, VS4) of reed-insulated wall tested by the authors (see Table 2) and a timber wall with glasswool insulation that was studied by Kukka & Miljan (2009).

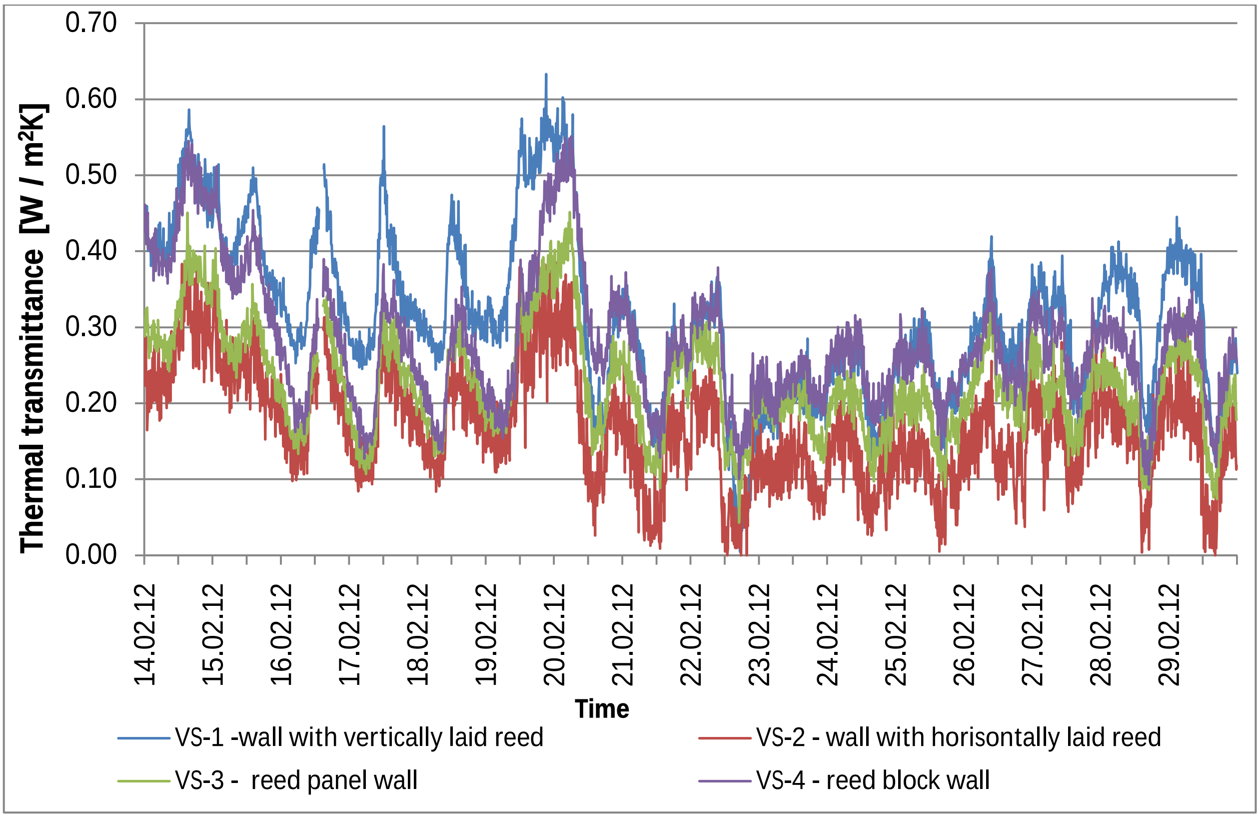
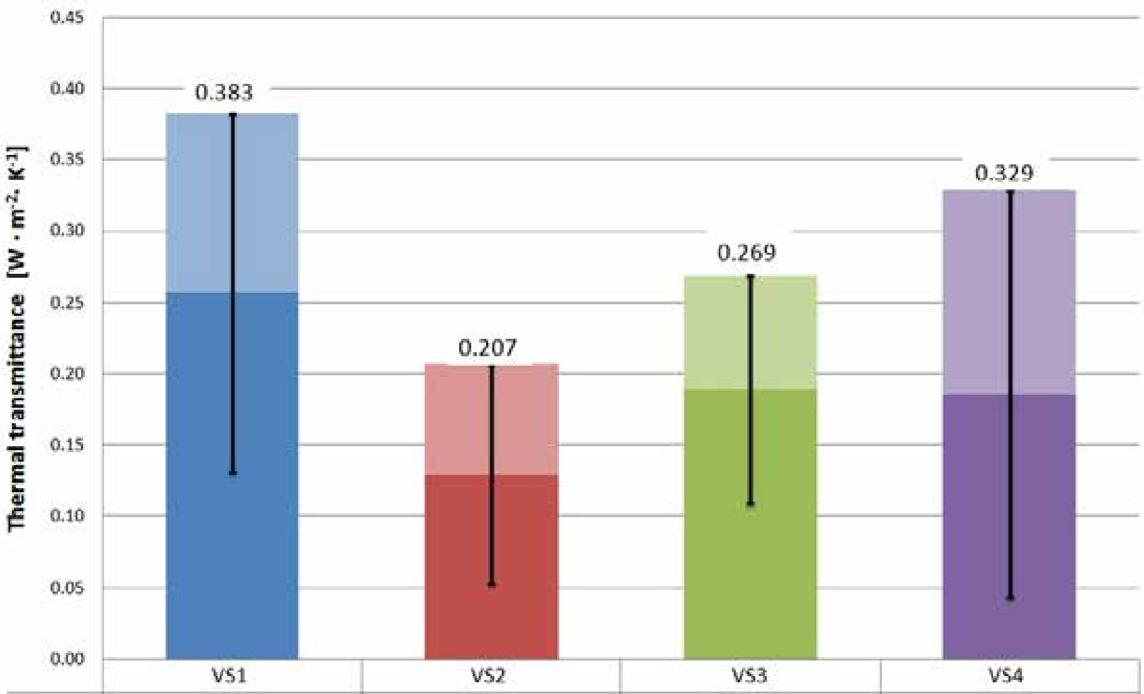


Figure 9. Fluctuations in thermal transmittance (*U*) of the different test walls during the second half of February 2012.



	VS1	VS2	VS3	VS4
s	0.126	0.077	0.080	0.143
Umean	0.257	0.130	0.189	0.186

Figure 10. Values of thermal transmittance (U_d) calculated for the different test walls from the data plotted in Figure 9, using Equation 2 (after Miljan & Miljan 2012c).

facilitate convective air movement inside the wall and, thus, heat transfer across it. Also, this wall type contains the smallest quantity of reed insulation per square metre (Table 1) because we were unable to compress the reed any farther when it was laid vertically. Comparison of the thermal transmittance values obtained for the walls with vertically (VS1) and horizontally (VS2, VS3) laid reed reveals clear differences (Figure 10). Wegerer & Bednar (2011) mention a manufacturer's requirement that, when using a reed mat as lathing to provide insulation on the interior sides of walls, the mat must be placed so that the reed stems lie horizontally. Unfortunately, no justification is given for this requirement.

When calculating the energy consumption of buildings in Estonia we must comply with the "minimum energy performance requirements" set by the standard RT I 2007 (Riigi Teataja 2007). This sets the maximum value of thermal transmittance (U_d) for external walls at 0.2–0.25 W m^{-2} K^{-1}. Of the four wall types incorporated into the test house, the horizontally laid reed wall (VS2) is the only one whose U_d value is compliant.

If a house is to be built using reed as an insulation material for the external walls, our results indicate that the best outcome in terms of thermal resistance will be achieved by using loose reed laid horizontally. On the other hand, the advantage of shorter construction time makes reed blocks an attractive alternative for which the disadvantage in terms of thermal resistance could readily be overcome by constructing thicker walls.

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Author for correspondence:
Matis Miljan, Department of Rural Building, Estonian University of Life Sciences, Tartu, Estonia.
Tel: +372-5155013; Email: matis.miljan@emu.ee