# Thermal Performance
# of Selected Building Details

Prepared for the
**Leonardo Partnership**
**for Strawbale Building II**

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## Content

## Introduction

The following work consists of thermal simulations of selected construction details, used in the world of straw building. With the aim to support the Leonardo Partnership for Strawbale Building, the intent has been twofold:

- To characterize the construction details from the thermal performance point of view,
- To support the training process by highlighting, illustrating and contrasting physical processes that have influence on the design decisions

## Notes

All the simulations were performed using THERM 5.2.14 Finite Element Simulation software, developed by Lawrence Berkley National Laboratory.

For the determination of the air cavity Keq (equivalent thermal conductivity) in accordance to the ISO EN 6946, the Kornicki Air Cavity Calculator was used in the case SSS wall simulation.

The modeled details were supplied by members of the Leonardo Partnership for Strawbale Building.

Material conductivities were supplied by the project members. Thermal conductivity of straw has been specified as 0.052 W/mK, which is a value accepted by German building codes for straw perpendicular to the heat flow.

For the window installation psi value calculations, a homogenous block with thermal conductivity of 0.035 W/mK was used in place of glazing. This has no impact on the installation psi value.

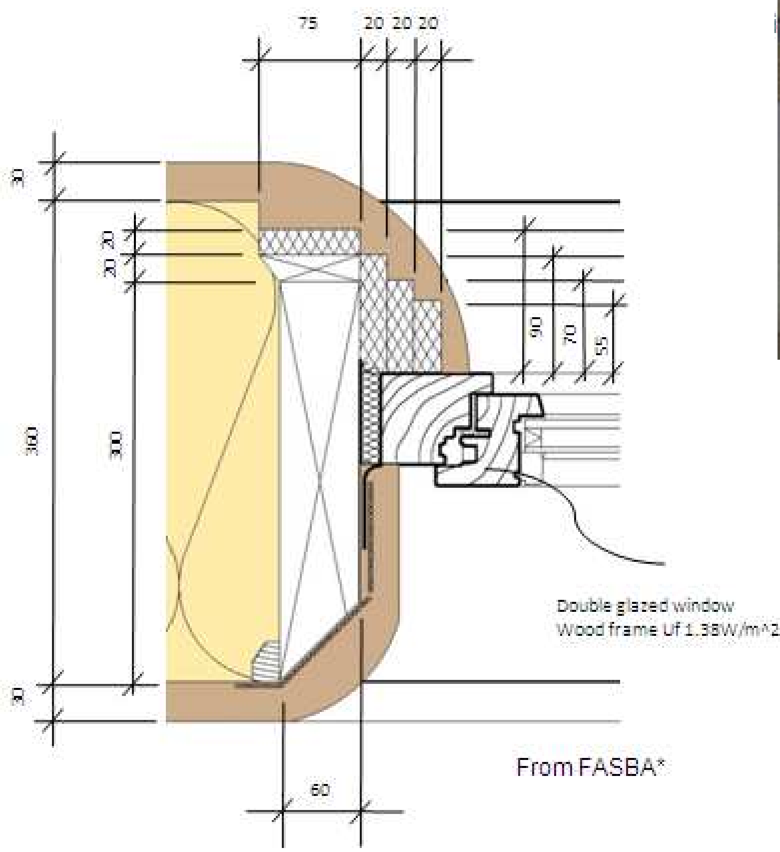
The windows installation psi value was calculated from the window glazing unit size, following the Passive House Institute (PHI) convention.

# Window installation – FASBA jamb

In highly insulated buildings, the heat loss due to thermal bridging gains on importance. One of the places where such phenomenon takes place is window frame. The way in which a window is installed in the wall can play a significant difference to the building heat loss and thermal comfort.

## A case study with the help of software modeling

The question whether additional thermal protection of the window frame makes a difference was investigated with the help of software modeling. Three cases were specified for a double glazed window with a wooden frame, fitted to a wooden upright in a straw bale wall. All the cases were based on the window jamb details, originally developed by FASBA.

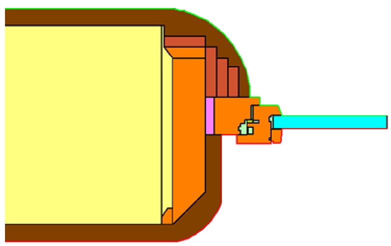



From FASBA*

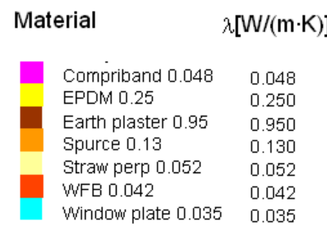
**Modeled scenarios**

In the case A, a wood fiber board (WFB) was used to provide additional thermal protection to the window frame (original FASBA design). In the case B, the WFB were replaced with a dense earth plaster. In the case C, there is no additional thermal protection of the frame.

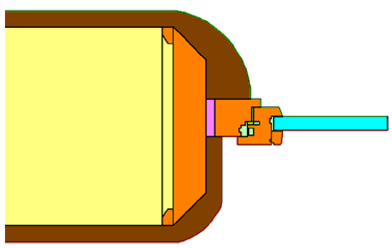
A



Window frame covered by Wood Fiber Boards

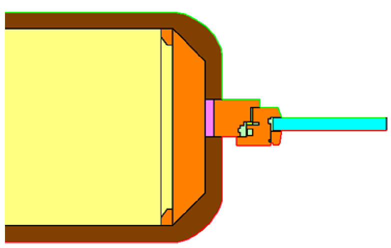



B

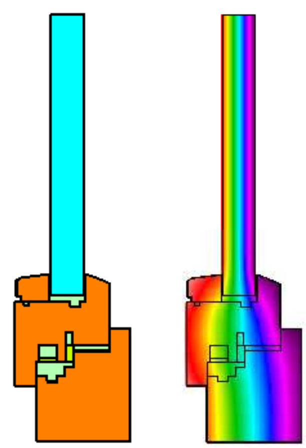


Window frame covered by earth plaster

C



No additional insulation of the window frame

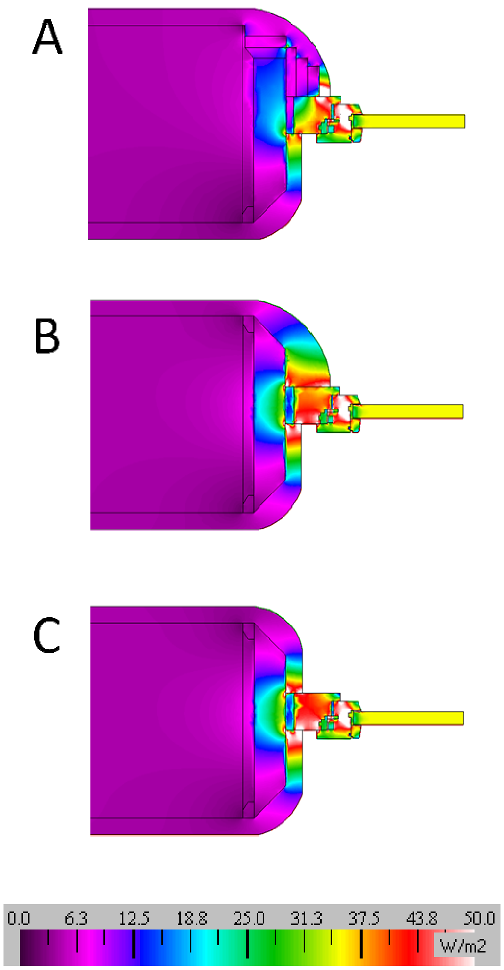


Modeled with a double glazed, wood frame window:
Uframe = 1.38W/m^2K*

*A 24mm thick insulation panel with thermal conductivity of 0.035W/mK has been used in the place of double glazing.

**Heat flux**

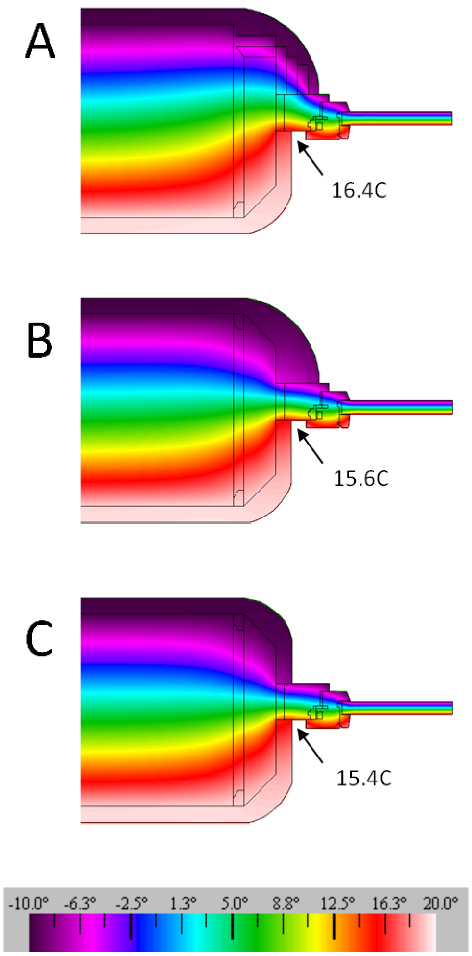
The magnitude of the heat flux can be seen on the visualization below. The simulation shows that the density of the heat flux through and around the window frame has been significantly reduced in the case A (WFB) when compared to cases B (dense plaster) and C (no additional protection).

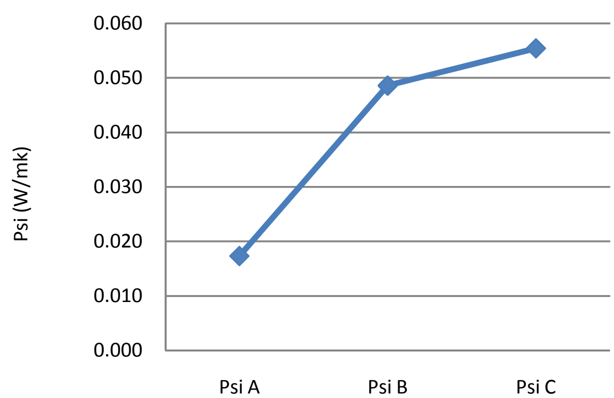



The wood fiber boards reduce the heat flow from the internal to the external environment. The earth plaster (case B) is not able to fulfill the same role. The exposure directly to the exterior (case C) leads to even higher heat flow.

**Psi value and Temperature profile**

The actual influence of the thermal bridge is quantified by the Psi value, which serves as a correction factor for the whole building heat loss calculation. Higher Psi value means higher heat loss through the junction.




| Psi installation | | |
|---|---|---|
| Psi A | 0.017 | W/mK |
| Psi B | 0.049 | W/mK |
| Psi C | 0.055 | W/mK |

The results show that the use of wood fiber boards (case A) can improve the installation psi value more than three times, when compared to the window frame exposed directly to the external environment (case C). Conversely, covering the window frame with earth plaster (case B) does not make a big difference from the direct exposure of the frame to the exterior.

The lower installation psi value is also reflected in higher surface temperature of the junction. This contributes to the thermal comfort of the building occupants and prevents potential condensation in the corner, leading to the danger of mould growth.

## Conclusion

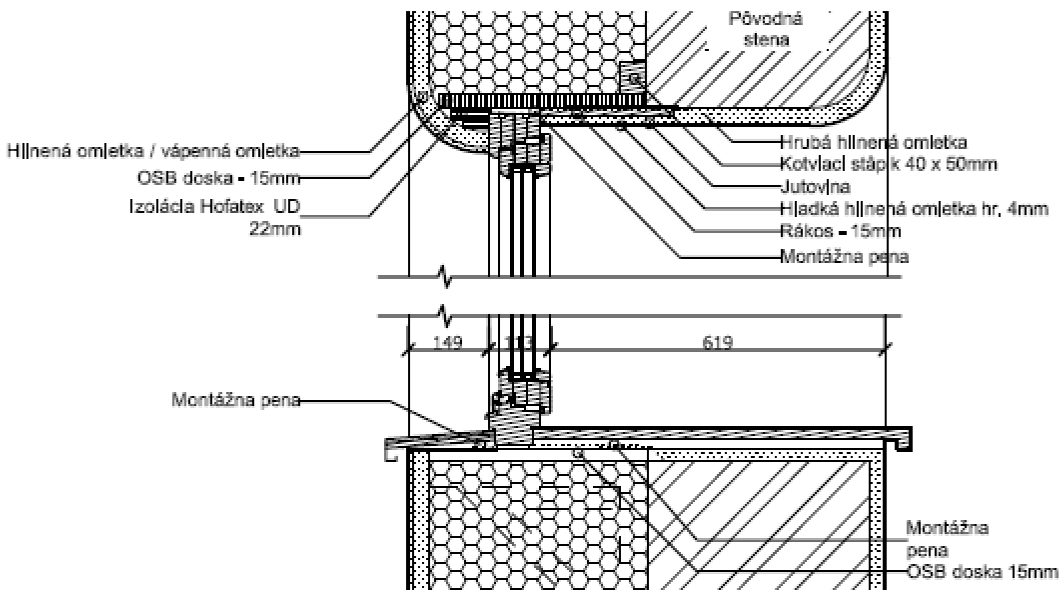
It can be concluded that from the heat loss and thermal comfort point of view, the use of the wood fiber board is justified. The window frame with additional protection benefits from lower installation psi value and higher surface temperatures.

# Position of windows in the wall

The position of a window in the wall can have a great influence on energy losses. This can be especially important when renovating an older building, for example in the case of the 'strawbale wrap'. It is a good practice to move windows and place them in the main insulation layer. This is done to reduce the thermal bridging around the window installation. To what extent is this important?

## A case study with the help of software modeling

The significance of such step can be seen on windows installed during a house renovation, using the straw bale wrap technique, in Brestovec, Slovakia. The original windows were removed and new ones were fitted in to OSB boxes, placed in the straw layer.



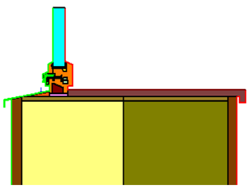

From Marian Ontkoc

From Marian Ontkoc

### Modeled scenarios

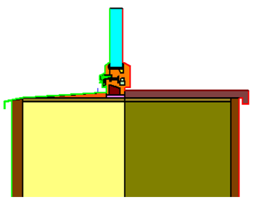
An analysis with the help of software simulation was performed. Four scenarios were specified for different positions of windows in the wall. The simulation was made with external temperature of -10C and internal 20C:

A



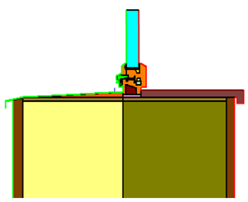
**Position A**
Window in the middle of insulation


B

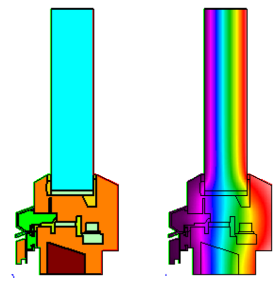


**Position B**
Window at the inner edge of insulation

C

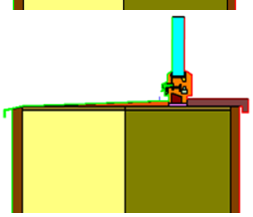


**Position C**
Window at the outer edge of masonry



Modeled with Optiwin Zwoa2Holtz PHI certified window.
wooden frame, cork insulated, triple glazed, Uframe (sill) = 1.05W/m^2K*

D

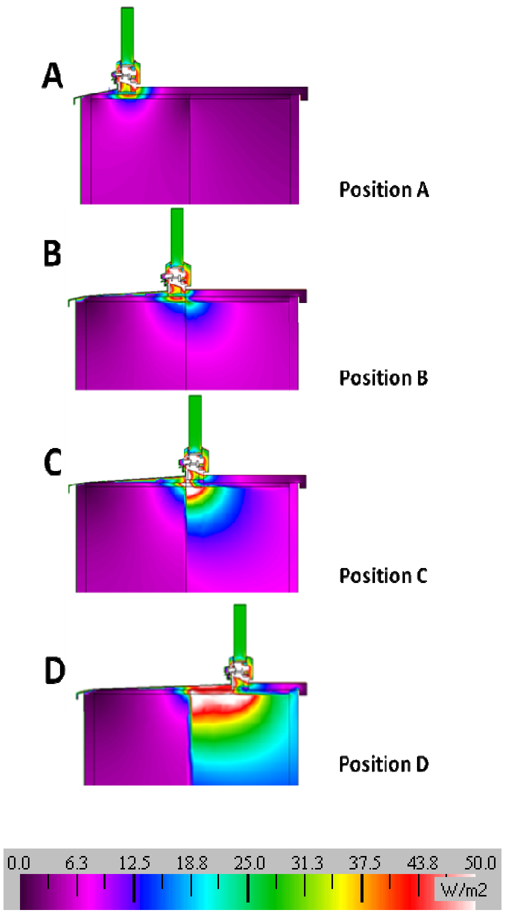


**Position D**
Window in the middle of masonry

*A 48mm thick insulation panel with thermal conductivity of 0.035W/mK has been used in the place of triple glazing.

**Heat flux**

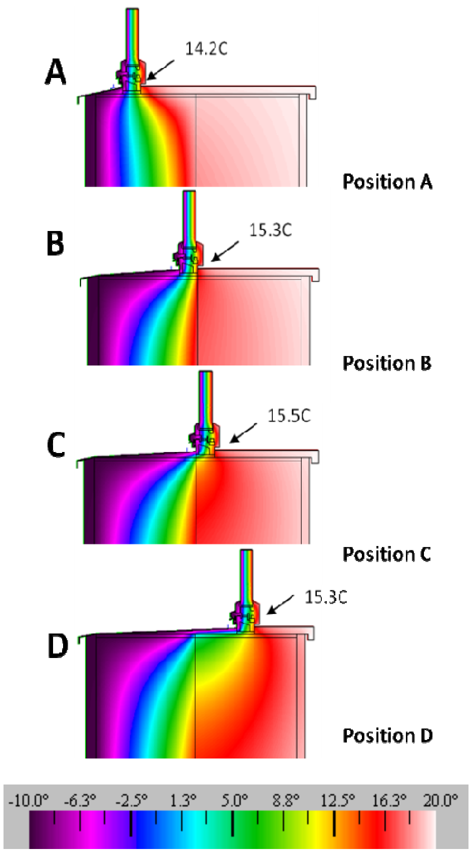
The simulation shows that with increasing distance of the window from the insulation layer, there is an increase in the heat flux through the wall / window junction.

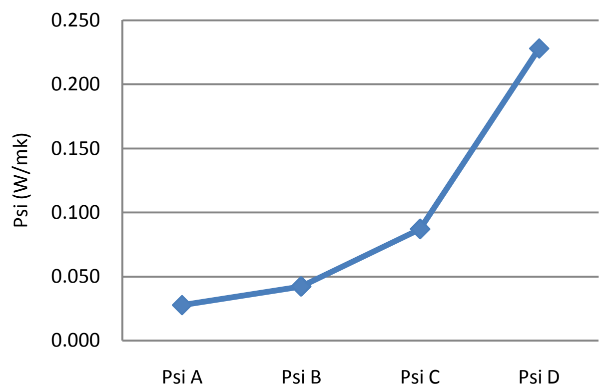



The heat flux is highest at the original position of the window (case D). The heat flows through the layer with the higher thermal conductivity (masonry) directly to the external environment and the insulation (straw) is doing a little to prevent this. The non optimized placement of the window leads to significant thermal bridging and associated thermal losses.

**Psi value and Temperature profile**

The actual influence of the thermal bridge is quantified by the Psi value, which serves as a correction factor when calculating the overall fabric heat loss with the help of U-Values. Higher Psi value means higher heat loss through the junction.




| Psi installation | | |
|---|---|---|
| Psi A | 0.028 | W/mK |
| Psi B | 0.042 | W/mK |
| Psi C | 0.087 | W/mK |
| Psi D | 0.228 | W/mK |

The simulation shows that the difference in Psi value between cases A and D is more than eighth fold. This would lead to a significant increase of the overall U-value of the building envelope.

It is also interesting to notice that with the increase in the psi-value, there is an increase in the temperature of the actual junction. While generally higher junction temperature is a positive thing, in this case this is a symptom of the increased heat flux around the window sill into the external environment. A second look shows that in the case D, the temperature in the masonry is much lower than in case A, with all the negative associated aspects (i.e. interstitial condensation or frost damage).

From this point of view, the change of the window position is justified.

## Conclusions

In summary, it can be said that there can be significant differences in energy losses, depending on the window position in the completed wall. From the heat loss point of view, windows should be placed in the insulation layer. While this may not always be possible (for example due to economical or aesthetical reasons), the builder / investor should be aware what impact the alternative design solutions can have.

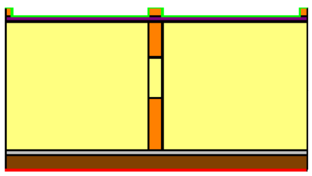
It is also interesting to note that higher psi-installation value does not necessarily mean lower internal surface temperature of the actual junction, as the increase in the psi-installation signifies increase of the heat flux through the junction. The value is just a correction factor for U-value calculations.

# Wall U-Values

## Design and Build Quality Considerations

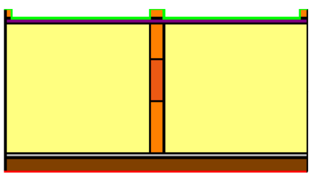
The choice of materials used to fill voids in walls (such as space between posts) can have a significant influence on the wall performance. The six examples below were examined from the thermal performance point of view with the help of software simulation.

**A**



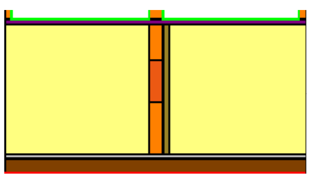
Cavity filled with straw (assumed density the same as straw bales)

**B**



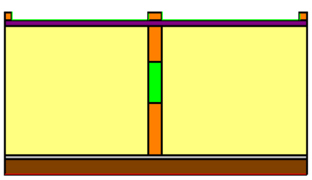
Wood Fiber Boards (WFB) between posts

**C**



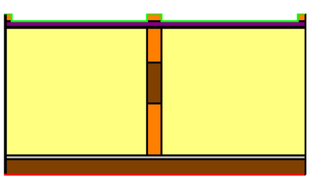
WFB + OSB between posts

**D**



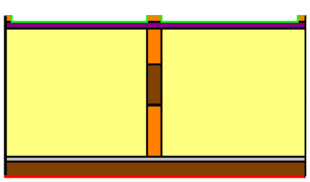
Air cavity between posts*

**E**

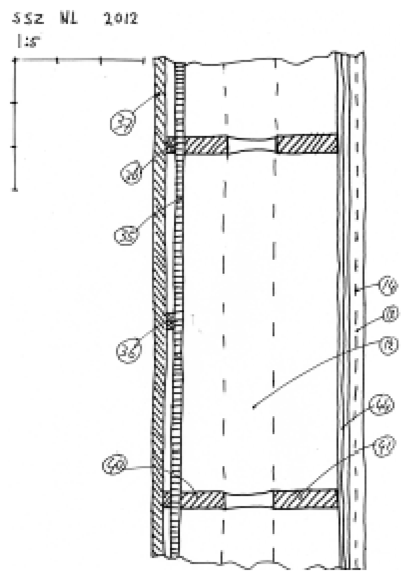


Cavity filled with earth / straw mix (λ 0.47 W/mK)

**F**



Cavity filled with earth loam (λ 0.95 W/mK)




From Wouter Klijn

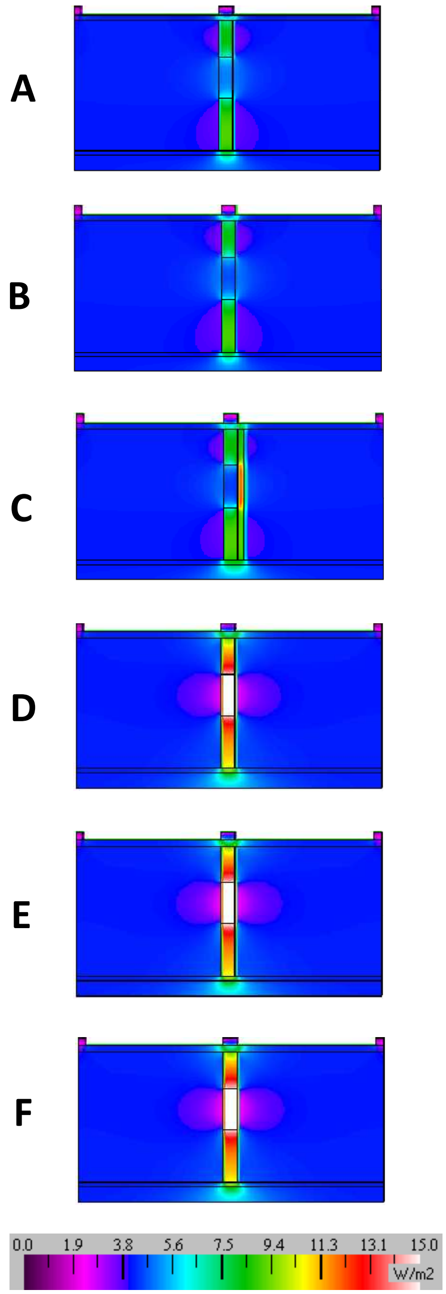
| Material | λ[W/(m·K)] |
|---|---|
| Earth plaster 0.95 | 0.950 |
| Spurce 0.13 | 0.130 |
| Straw perp 0.052 | 0.052 |
| WFB 0.042 | 0.042 |
| OSB 0.13 | 0.130 |
| Cavity 0.624 | 0.624 * |

Temperatures: Internal 20C
External -10C

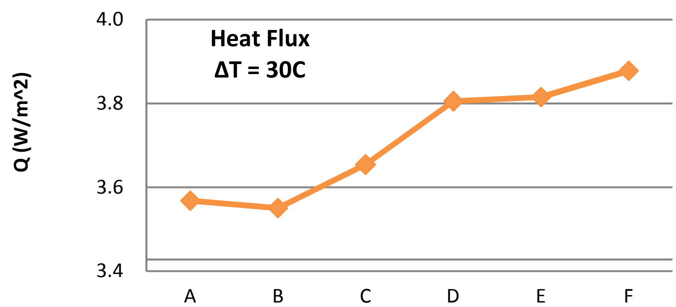
* The air cavity thermal resistance determined as per ISO EN 6946

**Simulation - Heat flux**

The simulation shows that cases with the cavity filled with the earth / straw mix, earth loam and air (D, E, F) have higher heat flow through the post area. The difference between the lowest (case B) and highest (case F) heat flow reaches almost 10%. The incorporation of the OSB board (case C) has much less influence.




This is expected result; the dense earth loam (case F) has thermal conductivity about 7 times higher than wood and 18 times higher than straw. Adding straw to the mix (case E) can limit thermal conductivity of the loam, but its properties are still way above thermal conductivity of compressed straw or wood fiber board. The situation is similar in the case of the air cavity (case D). While air has very low thermal conductivity, in combination with radiative and convective forces across the cavity the heat transfer increases*. In this case, the conductivity of the air cavity is similar to that of loam, rather than that of insulation materials.



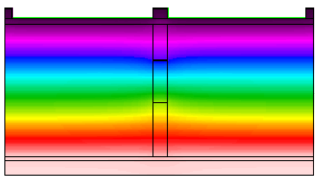

| | Heat Flux (W/m^2) | | |
|---|---|---|---|
| **A** | 3.57 | 100 | % |
| **B** | 3.55 | 100 | % |
| **C** | 3.65 | 102 | % |
| **D** | 3.81 | 107 | % |
| **E** | 3.82 | 107 | % |
| **F** | 3.88 | 109 | % |

* The three combined ways of heat transfer are expressed in equivalent heat conductivity (Keq), determined in accordance to ISO EN 6946

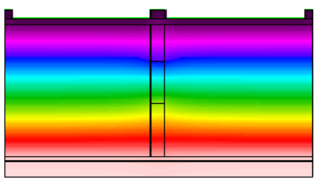
**Simulation - Temperature profile and U-Values**

The increase in the heat flux is directly reflected in the increase of the U-Values. Again, the difference between the lowest and the highest case is almost one tenth of the value (U = 0.1416 W/m^2K in the case B against U = 0.1539 W/m^2K in the case F). This is a difference that can be crucial, especially when aiming to construct a house with high energy performance, such as the passive house. Thermally, the use of the OSB board seems to be justified, if it is needed for structural purposes.

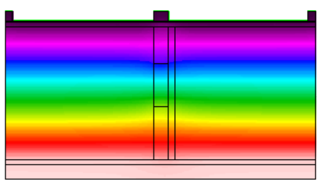
**A**



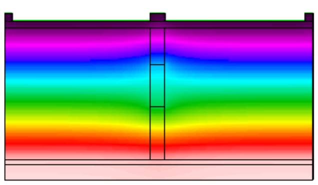
**B**



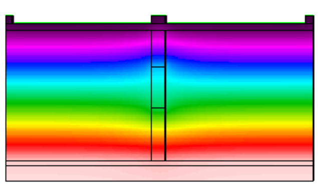
**C**



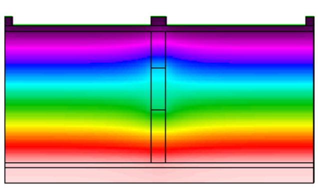
**D**

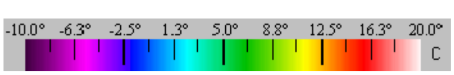


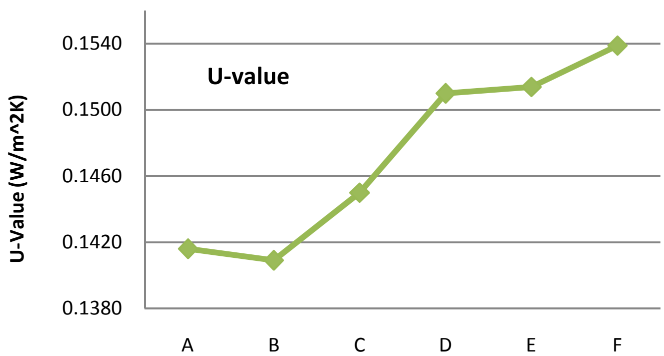
**E**



**F**






| | U-Value (W/m^2K) | | |
|---|---|---|---|
| **A** | 0.1416 | 100 | % |
| **B** | 0.1409 | 100 | % |
| **C** | 0.1450 | 102 | % |
| **D** | 0.1510 | 107 | % |
| **E** | 0.1514 | 107 | % |
| **F** | 0.1539 | 109 | % |

**Thermal Vs overall performance of the wall**

In the studied examples, the simulation shows that the increase in U-Value due to the air cavity is comparable to the increase due to the loam. However, it is important to keep in mind that the thermal performance is just one (very important though) aspect of the fabric characteristics. If seen in wider context, air voids in the wall can bring other issues when compared to loam.

Firstly, under the right conditions (size, location in the wall) voids can lead to convection currents within the wall*. This is a negative thing, especially if the current bridges the insulation layer. Even worse scenario is if convection causes chimney effect, leading to draught through the wall. This leads not only to a draughty house, but also to sucking the moist air into the wall, with the danger of interstitial condensation. Loam can prevent creation of convection currents in the wall.
Next to this, in the environment with the same temperature and relative humidity, loam is able to hold more moisture than air as it is hydrophilic. It acts, therefore, as a moisture buffer, preventing water from condensing in the wall.

Due to the two aspects, it can be said that while the simulation shows that the thermal performance of the wall with the air cavity is comparable to that of loam, loam is a potentially safer design if wider context is considered too. Each situation is context dependant and has to be considered as such (i.e. in the studied examples a low cavity between the wooden posts would cause less harm than a tall channel with the same outline). The questions of practicality during the build can also play a significant role and have to be considered too.

In any case, the simulation also makes evident that materials such as straw or wood fiber based products (cases A, B and C) represent better solutions than air or loam (D, E, F), as they are performing well thermally, prevent convection currents and have some moisture buffering capacity too.

**Conclusions**

The simulation shows that designing with attention to material properties and careful detailing plays important role in the building fabric performance. A space between wooden posts benefits from additional insulation. Straw or wood fiber products perform better than loam based fillings or air cavity.
While loam performs thermally to the comparable standard as the air cavity, unfilled void can lead to other issues. The situation has to be seen in wider context; a good design should find the balance between, often conflicting, requirements.

* The simulation does not take to account any convection through the wall. It is limited to consideration of the convective and radiative transfer of heat across the cavity outline only.

## Assumption and limiting factors

Due to the nature of straw (a natural material with specifically high cell size, limited process control during the production of bales), the simulations have been based on idealized assumptions. In reality, the following would impact on the thermal performance:

1) Idealized assumption about the homogeneity of straw (density, orientation). In reality, straw in and between bales may not be perfect. This would have an impact on the uniformity of the thermal conductivity across the mass of straw.

2) Idealized assumption about the way straw has been filled in / around construction details. In reality, this may not be perfect. This would have an impact on the overall thermal performance.

3) Due to 1) and 2), the overall heat transfer due to *convection* can be higher than in ‘standard’ materials.

4) The possibility to cater for this convection in THERM is limited. (THERM considers heat transfer mainly via conduction as it were a solid material). The *convective* and *radiative* forces are taken into account too, if a material is specified as a cavity. However, this aspect is tuned for different applications, such as windows / glazing systems.

5) There is no way how to simulate convection <u>through</u> the wall in THERM.

The limitations would be less pronounced in the case of the FASBA and Brestovec window installations, as the actual detail assembly consist mainly of solid materials.

Next to this, it would be fair to note that even if probably more pronounced with straw, these idealizing assumptions play a role even when simulating with ‘standard’ materials.

Where is the point up to which can straw be considered for a standard material and beyond which it cannot?

## Further work

To take the above work further, the calculated psi values can be entered into energy calculations software tools, such as PHPP (Passive House Planning Package), SAP (Standard Assessment Procedure - UK), or Energie (CZ). This would allow quantification of the impact on the overall heat loss, with implications on the energy demand, $CO_2$ emissions and cost of heating.

# Relevant literature

EN ISO 10077-2: 2012 Thermal Performance of windows, doors and shutters – calculation of thermal transmittance. Part 2: Numerical method for frames

EN ISO 10211:2007 Thermal bridges in building construction – Heat flows and surface temperatures – Detailed calculation

EN ISO 6946: 2007 Building components and building elements – Thermal resistance and thermal transmittance – Calculation method

BRE 497: 2007 – Conventions for calculating linear thermal transmittance and temperature factors

BRE 443: 2006 - Conventions for U-value calculations

Calculating Window Performance Parameters for Passive House Energy Modeling
http://www.passivehouse.us/passiveHouse/window%20protocol02.25.12.pdf

Šubrt, R. a kolektiv, 2011. *Tepelne Mosty*. Praha: Grada Publishing

Certification criteria for Certified Passive House Glazing and Transparent Components
http://passiv.de/downloads/03_certification_criteria_transparent_components_en.pdf

Window Frame Certification Schedule
http://www.passiv.de/old/07_eng/03_cert/Komp/Anford_e/F_Anfor_e/F_Roadmap.pdf

THERM 2.0 User Manual
http://windows.lbl.gov/software/therm/Docs/Therm2.pdf