SIMULATION OF RELATIVE HUMIDITY, TEMPERATURE AND MODELLING OF MOULD GROWTH IN EXTERIOR WALLS ISOLATED WITH STRAW BALES IN A SOUTHERN SWEDISH CLIMATE

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ABSTRACT

There is a growing need for climate conscious constructions. Exterior walls isolated with straw bales are potentially a step in this direction. The material straw is locally produced, carbon neutral with good energy efficiency. However, there are risks with straw as a building material and susceptibility to mould is a major concern in temperate climates.

The purpose of this study was to investigate the risk for mould growth in exterior walls isolated with straw bales, which also entailed an investigation of the conditions for mould growth. Through computer simulations in the software Wärme und Feuchte Instationär (WUFI) the relative humidity and temperature in vented and unvented exterior straw bale walls were examined in a southern Swedish climate. The relative humidity and temperature where then applied to three different mould models: Isopleth-, Folos 2D- and Mould Resistance Design (MRD)-model. A parametric study was also conducted to ascertain the most sensitive parameters for straw bales.

One of the primary objectives was to investigate whether there were any constructions that had no risk for mould growth. For the simulation of design solutions, 3 vented and 3 unvented constructions were used. The choice of design solutions was based on common straw bale constructions, but also unconventional solutions.

The study shows that common design solutions of straw bale constructions are likely to have a risk for mould growth. Ventilated, infrequently used straw bale constructions have less risk for mould growth.

INTRODUCTION

Straw bales as a building material have a history dating back to the late 1890´s in the USA, (Kay et al. 1990). In Sweden today an excess of straw is produced, according to Bernesson & Nilsson (2009) 300 tons of excess straw is produced in the Scania region of Sweden, due to the excess produced, straw bales are cheap (Lantbruksnet). When building with straw bales there are two methods: using the bales as insulating material between a structural frame or using the bales as load bearing elements (King 2003). Straw has many advantages: it is locally produced, it has good heat and sound insulating properties especially when coupled to the often large dimensions and it is carbon neutral (Deverell et al 2009; Nationalencyklopedin2014a, 2014b; Pruteanu 2010). The production of straw bales is a process that consumes little energy (Nilsson 1999).

There are risks connected to straw bale building as with all building materials. A commonly held view is that straw bale walls are fire prone but test performed in the USA of straw bale walls with clay plaster showed a fire resistance of over 2 hours (Intertek, 2007). According to Magwood and Mack (2000) the tightly packed bales contain little oxygen minimising the risk for ignition. As straw is an organic material there is also a risk of vermin infestation, this is a risk that must be taken seriously and accounted for in the planning phase. It is also important to fill in gaps and cracks to ensure that vermin are kept at bay (Homegrown (no date). Straw bales offer little nutritional value due to the fact that it comprises of the dried stalks of cereals whilst the nutrient rich grain has been harvested. The major concern when building with straw bales in a Swedish climate is the moisture risk. Straw is an organic material and therefore susceptible to microbiological attack. According to Johansson (2006) the presence of microbiological growth on building materials is associated with several problems like poor indoor air quality and the loss of building functionality. Investigations done by Viitanen (1996), show that there are a variety of microorganisms on building materials. Mould is the microorganism with the highest tolerance, also called the "primary colonizer", for this reason most studies focus on mould as is the case in this work.

The purpose of this study was to investigate with the aid of simulations in WUFI, whether it is possible to build houses insulated with straw bales in the south of Sweden that are safe from a moisture point of view, by extension this entailed studying the risk for mould growth. Evaluation of mould growth was done using three models: Isopleth model (Sedelbauer 2001), Folos 2D (Mundt-Petersen et al. 2012) and the MRD-model (Thelandersson & Isaksson 2013). To achieve simulations that could be seen to reflect reality a parameter study was also performed using WUFI.

THEORY

WUFI

WUFI is software for simulations developed by the Fraunhofer Institut für Bauphysik (2014). WUFI is used to perform humidity and heat transfer simulations in building contexts. Models may be constructed in 1D and 2D. WUFI is an iterative program that tries to solve a temperature equation and moisture equation simultaneously. In this study, WUFI 1D used. The program requires an input of design and material parameters. The output is temperature, relative humidity (RH) & water content. The physics and calculation method used in WUFI is based on a doctoral thesis by Künzel (1995). The suitability of WUFI has been investigated by Mundt-Petersen (2013); Harderup & Hägerstedt (2011). WUFI has been used in a variety of studies, including a study on moisture conditions in a straw bale wall performed by Danielewicz, et al. (2008).

Mould

Mould microorganisms function as degraders in nature. They are present on organic materials in nature and in the earth. Mould spores are assumed present on all surfaces and in the air irrespective of season and climate. Several studies, including Johansson (2006) and Sedlbauer 2001show that the main factors for mould growth are RH, temperature and the properties of the material surface. Mould growth is initiated when ambient temperature and RH triggers the mould spores to germinate and if the favourable conditions still exist a hypha is produced, the continuing growth and branching of the hypha produce a mycelium, eventually a conidiophore is formed and these structures produce and disperse spores thus starting the cycle anew. According to Johansson (2006), moulds can affect the health of the inhabitants in infested buildings, the greatest health risk is not physical contact with the mould but rather health affect produced by the fact that when mycelium grow they release volatile organic compounds into the air. These gases are what cause the typical musty odour associated with mould, this odour penetrates materials in the building remaining even after measures have been taken to eradicate the mould. The volatiles may also affect the human body in different ways depending on the mould species present and the susceptibility of the inhabitants; common ailments are allergic reactions, redness, mucous membrane irritation and headaches. The people most sensitive are the young, elderly and people with compromised immune systems.

For mould to grow a RH of 75% is needed in most cases. Different materials have different threshold RH for mould growth (Sedlbauer2001). There are materials that require less RH than 75%. Tests performed by Hofbauer et al. (2008), show that straw requires a RH of 70% and a temperature higher than 0 ° C (see Figure 1) to sustain mould growth. Temperature and RH are dependent, for example, a lower temperature requires a higher RH for mould growth. For mould to grow a lower RH is needed than for mould spores to germinate (Sedlbauer 2001). To be on the safe side the threshold value for growth is used. There are two concepts that are of importance to differentiate, initiation of mould growth and mould growth that damages function and/or health. This study does not take into account the loss of function instead focusing solely on the initiation of mould growth.

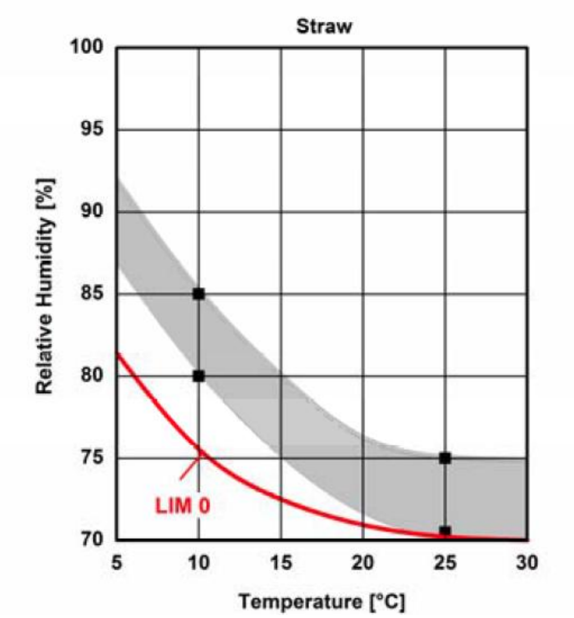

Figure 1 Isopleth showing critical range (grey) where mould spores can develop to mould for the material straw.LIM0(red)is also included (Hofbauer et al. 2008)

Mould models

Evaluation of the risk for mould was performed using three mould models: the isopleth model, Folos 2D and the MRD-model. The three models were selected based on their differences in predicting the risk for mould growth and their differences in visualising the risk. All mould models were scripted in MATLAB and plots were likewise made using MATLAB

The isopleth model is based on laboratory tests where the materials are tested to see when mould growth occurs on a material. A curve with RH on one axis and temperature on the second axis is produced (see figure 1). Sedlbauer (2001) produced isopleths for mould species that are considered dangerous to human health and the most common mould species found in a building context, the result was LIM0 (Lowest Isopleth for Mould) which can be seen as the absolute threshold for mould growth on an *optimal* medium (see Figure 2). A study by Hofbauer et al. (2008) produced material specific isopleths including for straw as can be seen in Figure 1.

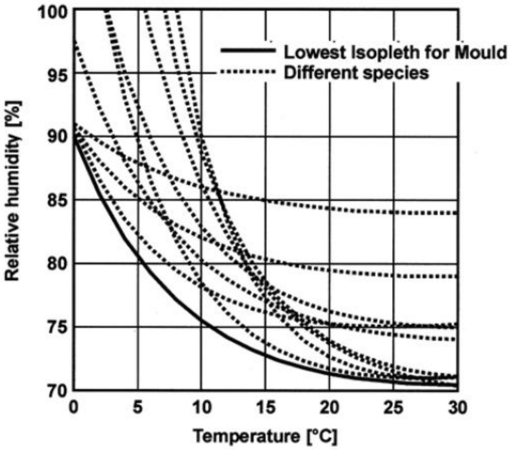

Figure 2 Isopleths for different species of mould (dotted) and LIM0 (solid) (Sedlbauer, 2001)

Folos 2D is strictly speaking not a mould model but rather a visual way to show mould risk, developed by Mundt-Petersen et al. (2012). The user decides which mould model that will be used to calculate a critical RH, then the period of time when RH> $RH_{critica}l$ is calculated. In this work LIM for straw from Hofbauer et al., (2008) is used.

The MRD-model developed by Thelandersson & Isaksson (2013) is based on a dose-response relationship, simply stated the model attempts to explain how a material is influenced over time by a certain “dose”. In this case the dose is combined temperature and RH as these are the two most important factors in predicting mould growth. The model uses 12 hour averages for temperature and RH. The model unlike the other mould models used takes into account the retardation of mould in unfavourable conditions. There are several mathematical equations that are the basis of the MRD-model. To apply the model a “critical dose” is needed. The critical dose is the amount of time it takes for a material in a reference climate (RH= 90 %, T= 20 °C) to reach a 2 (sparse but established growth with conidiophores beginning to develop) on Johansson’s (2006) mould rating scale. The equations coupled with the critical dose are used to calculate an MRD-index, which can be seen as an index indicating the risk for mould growth. A design has “failed” when MRD-index 1 is reached which is equivalent to Johansson’s (2006) mould rating scale of two. Thelandersson & Isaksson (2013) state that the equations they present are valid only until a MRD-index of one is reached, values over MRD-index 1 are included even though they are not completely accurate to give an indication of the state of the mould. In this study, a critical dose of 8.5 days Was used, this is the lowest critical dose reported by Thelandersson & Isaksson (2013) for wood. This means that the MRD-model used in this work is adjusted for wood and not straw. Straw and wood have similar properties but straw has a lower threshold for mould than wood does (Hofbauer et al., 2008, Sedlbauer 2001), therefore the reader should be aware that the values obtained from the use of the MRD-model are probably somewhat euphemistic.

SIMULATIONS

Parameter study

WUFI demands of the user that certain material and design parameters are defined in the simulation model, for several materials these parameters are pre-defined in the software but for straw bales, no such information existed. It became apparent that the parameters would have to be manually defined by the authors. A quick review of the literature showed that the parameters for straw bales had a significant spread; this is probably due to different growing locations, when the straw was harvested etc. The uncertainties present in the parameters for straw bales made a parameter study necessary. The first step was identifying which parameters were needed to create simulation models in WUFI. There existed for several of the design and material parameters a standard value in WUFI that was deemed correct. After identifying, the parameters that needed to be decided a literature review was performed to find a probable range of values (see Table 1). To study the effect of a parameter a maximum, minimum and standard value was designated and then simulations were carried out on a vented and unvented design solution using these values whilst the rest of the parameters were kept at their standard values (see Table 1). One important thing to note is the fact that certain parameters i.e. porosity are directly related to bulk density, these parameters were calculated from the bulk density therefore their max, min and standard value correspond exactly to the max, min and standard values for bulk density. The position that was monitored was in the middle of the straw bale to minimise the effect of the indoor and outdoor climate. The geographical location used for simulations was Lund and the climate data used was the integrated climate found in WUFI. The start temperature was set to 15 ° C, the start date for the simulations was the first of September and the simulation time was 10 years. After simulation, the results were plotted in MATLAB (see Figure 3 and 4) and the largest difference between the different values for a parameter was calculated, due to space restrictions only one set of plots is shown. Certain parameters that had a significant effect on the hygrothermal models were investigated further by simulating with the same methods as described above but selecting a larger set of values and investigating their effect on mould growth by using Folos 2D, for more details see Jeppsson & Ramberg (2014). Finally, the values to be used for further simulations were decided by discussion between the authors.

Table 1
Table over main parameters investigated. Parameters in italics were subjected to two parameter studies before the selected value was reached.

Parameter	**Min val.**	**Std. val.**	**Max. Val.**	**Max diff. RH (%) vented**	**Max diff. RH(%) unvented**	**Selected value for the parameter**
Bulk density [kg/m³] + parameters connected to bulk density: porosity, reference water content, free water saturation^{a,b}	90	105	120	7.75	10.47	105
Porosity^{c}	0.86	0.88	0.90	-	-	0.88
Heat capacity^{a} [J/kgK]	-	1800	-	-	-	1800
Heat conductivity, dry^{a,b}[W/ m^{2}K]	0.03	0.045	0.067	1.44	1.06	0.045
Water vapour diffusion resistance factor^{d}	1.0	1.5	2.0	1.21	2.35	1.5
Reference water content^{e} [kg/m³]	18	21	24	-	-	21
Free water Saturation^{e} [kg/m³]	54	63	72	-	-	63
Water absorption coefficient^{a,,f}[kg/m$^2\sqrt{s}$]	0	0,01	0.05	7.60	22.47	0.01
Heat conductivity, moisture-dependent^{a} %/M-%	-	4	-	-	-	4.0
Typical built-In Moisture^{b,g} [kg/m³]	10	15	20	18.63	18.67	15
Short-wave radiation absorptivity^{h}	0.2	0.5	0.7	11.48	10.74	0.6
Bale thickness^{i} [m]	-	0.46	-	-	-	0.46
Rain reduction factor^{d}	0.3	0.5	0.7	0.22	12.27	0.5
Moisture source^{j} [%]	0.5	1.0		0.89	0.47	1.0
Air changes^{k} [ac/h]	1	30	100	12.45	-	30
Orientation	North	South	-	2.52	15.96	South

a: Danielewicz, et al. (2008), b: Ashour (2003), c:Adapa et al (2009), d:WUFI Wiki (2014) e:Lawrence et al (2009), f: Evrad et al. (2012), g: WUFI Forum (2014), h: Nevander & Elmarsson (2006), i: Johansson (2003), j:ASHRAE (2008), k: Falk (2010)

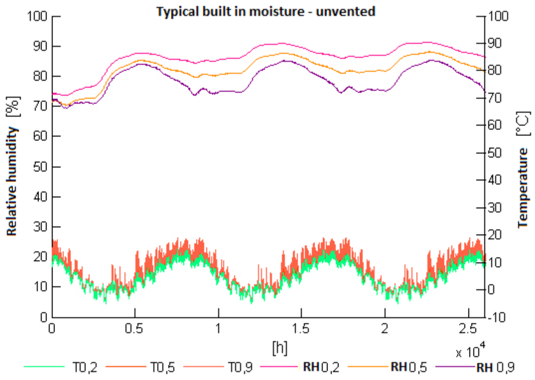

Figure 3 Figure over temperature and RH over time for an unvented structure. T0/RF0 shows temperature and RH at a typical built in moisture level of 0 kg/m^3. The rest of the values follow the same pattern as does Figure 4.

Design solutions

The selection of design solutions was based on common straw bale constructions but also on unconventional solutions involving plastic membranes and air gaps. Two of the design solutions tested are shown in Figures 5 & 6. In the study a total of six design solutions were tested, here only two are presented-The position that was monitored was the edge of the straw bale closest to the outdoor climate as this is according to Mundt-Petersen (2013) the most moisture critical position. The climate data used was actual climate data from Lund for the period 1990-09-01 to 1998-09-01 that had been manipulated to reach a RH of 100 % at least once every three months (P. Wallentèn 2014, pers. comm. 25 April). The results of the simulation were analysed by the mould models leading to four different plots per design solution as can be seen in Figure 7-14.

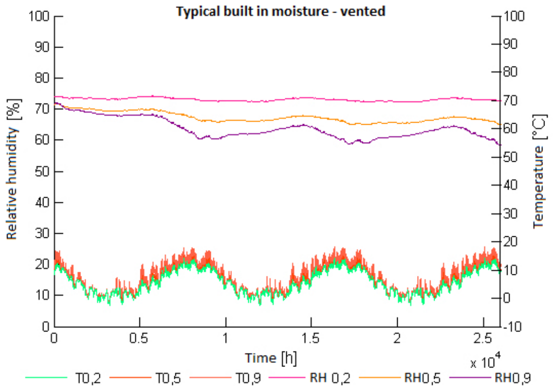

Figure 4 Figure over temperature and RH over time for a vented structure

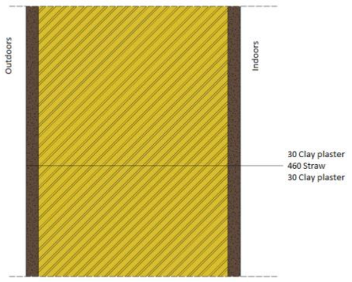

Figure 5 Design solution 1(unventilated)

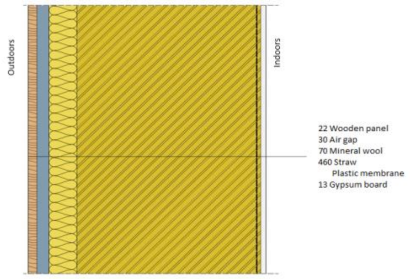

Figure 6 Design solution 2(ventilated)

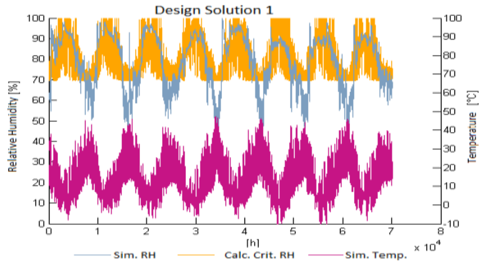

Figure 7 Temperature, RH and critical RH for design solution 1

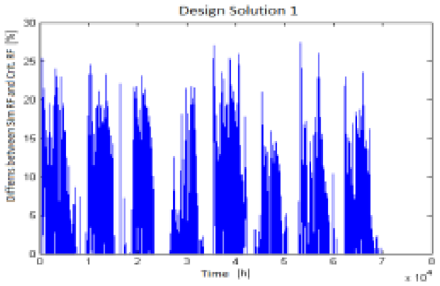

Figure 8 Time period when RH>RHcrti Design. Solution 1

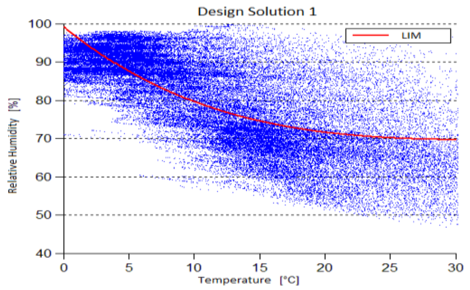

Figure 9 Isopleth design solution 1

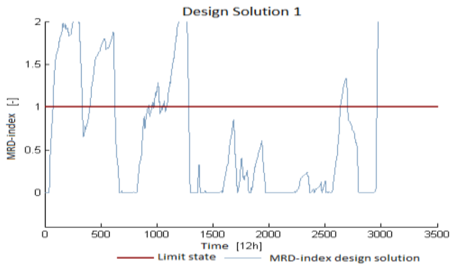

Figure 10 MRD-index for design solution 1

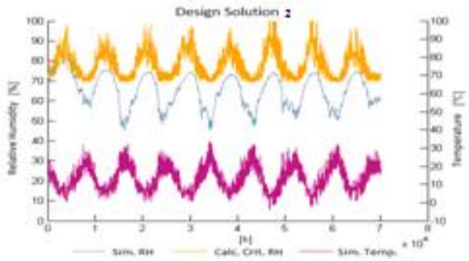

Figure 11 Temperature, RH and critical RH for design solution 2

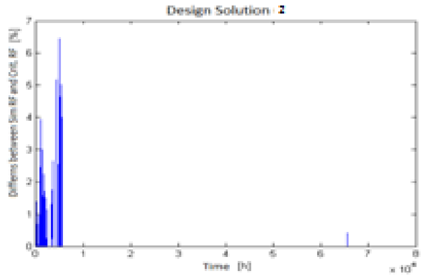

Figure 12 Time period when RH>RHcrti Design. Solution 2

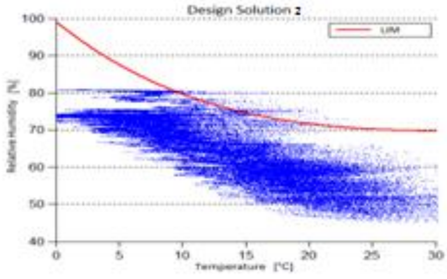

Figure 13 Isopleth design solution 2

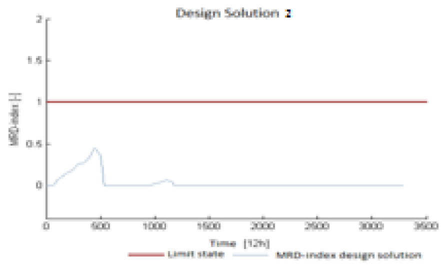

Figure 14 MRD-index for design solution 2

DISCUSSION AND RESULT ANALYSIS

Parameter study

The authors believe that the largest source for error is to be found in the parameters for straw bales. The parameter study was performed to try to eliminate these errors but there is a lack of experimental data on the hygrothermal properties of straw bales. In some cases extremely limited information was found, making comparison between different values impossible and forcing the authors to rely on a limited amount of sources. In this study no experimental investigations were carried out by the authors to determine the parameters for straw bales, this creates an uncertainty over how the values for straw bales produced in the Scania region of Sweden are in relation to the parameters used in this study. A problem when constructing hygrothermal models with the material straw is the inherent variation of the parameters. This property means that the results obtained can at best be seen as averages. Another source of error is that the authors did not take into the account is the covariance of the material parameters. The water absorption coefficient illustrates the problems encountered with the parameter study well, the different values caused results that were extremely difficult to analyse. A natural assumption is that an increased transport of water in the liquid phase will lead to a higher RH. The results on the other hand showed that this parameter behaved extremely erratically, it was investigated whether WUFI when using this parameter to estimate liquid transport coefficients for suction and liquid transport coefficients for redistribution was generating coefficients that were incorrect but no obvious source of error was found. In this case, the authors decided to use a value that lay between the extremes. The water absorption coefficient highlights the gap that exists with a lack of experimental investigations and statistical analysis of the material parameters for straw bales that would be suitable for future studies.

WUFI

Software WUFI has been used continuously during the study no comparison was made between the data produced using WUFI and other simulation software. The output of the simulations is assumed to be correct. The program's accuracy has been assumed to be correct, which has been shown by others publications. The authors have endeavoured to build up correct hygrothermal models, but there is a risk that errors were made despite this. Ann obvious limitation is that the complex conditions prevailing in reality only can be simulated on a very simplified level. The climate data used is assumed to be correct. There is a criticism of the integrated climate data in WUFI, because extreme values have been removed. The climate data found in WUFI is an average and its use can be questioned. Climate data that has been manipulated to create extremes has also been used, again it can be questioned how representative this data actually is. As with all climate data there is a built in error originating from errors in the measuring instruments. The simulations were done in one dimension which is of course a major simplification. Both temperature and moisture movements are two- or three-dimensional. The impact of phenomena like thermal bridges, leaks and connections have not been considered. One can assume the thermal bridges that are present give rise to a higher temperature locally which in turn leads to a lower RH. Whether this is positive or negative from a mould standpoint is difficult to say. During the study few convergence errors arose, the largest value being 18 convergence errors this with a simulation time of 10 years. The convergence errors were obviously not a source for significant erroneous results. Differences between the balances after each simulation were roughly equivalent, suggesting that this was also not a major source of error.

Mould models

To evaluate mould risk three different models have been used. The MRD model presented in this study is designed to be used for wood. It is possible to manipulate the equations used to be valid for other materials; however, neither the time nor the resources existed to this. The choice was made to use model even though it is adjusted for wood. This obviously gives results that are not completely correct for straw. The choice of using the model was done due to the fact that it distinguishes itself from the other models in the study. Because straw is more susceptible to mould than wood, the results of the MRD model are considered to be euphemistic. The isopleth for straw comes from only one source. If this isopleth would prove to be incorrect, the assessment of mould risk in the isopleth model and the calculated critical relative humidity in Folos 2D would be incorrect.

Design Solutions

The results shown in this paper are for design solution 1 (Figure 5) the most common constructions and for design solution 2 (Figure 6) an unconventional solution, which also showed the “best” and the “worst” results in the study. Figures 7 and 8 show that for design solution 1, actual RH exceeds critical RH for long periods of time and by as much as 27 %. The isopleth for design solution 1 (Figure 9) shows a large amount of simulated hours that lie above the LIM for straw. The MRD plot (Figure 10) shows that the limit state is quickly surpassed. The overall conclusion being that design solution 1 is prone to mould growth. Design solution 2 shows more promising results, Figure 11 and 12 show that RH exceeds the critical RH for an initial period and then only by about 6,5 %. The isopleth (Figure 13) shows similar results with only a few simulated hours exceeding LIM for straw. According to the MRD-model design solution 2 is risk free from a mould point of view (Figure 14). The results from design solution 6 seem to indicate that this construction could be feasible in a southern Swedish climate, especially if measures are taken to lower RH during the initial period, for example building with dry straw bales. The results presented are the “best” and the “worst”, there is however a general trend, with the overall results of the study showing the importance of having a ventilated structure when building with straw bales in a southern Swedish climate. The unventilated structures were shown to be extremely risk-averse from a mould point of view with many simulated hours that exceeded the thresholds for mould growth. Even when unconventional methods are used like the addition of a plastic membrane, the unventilated structures are risky. The ventilated structures demonstrate much better results. This shows the importance of having an air gap, which is unusual today when building with straw bales. The authors believe that it is an unnecessary risk to build a structure without an air gap in a Swedish climate.

During the study, the authors had contact with several inhabitants of straw bale houses that reported little or no mould problems, which is contrary to the simulation results. The authors speculate that one reason for this is could be that a positive pressure exists in the buildings therefore pushing air out of the building and leaving the inhabitants unaware of the mould problem that exists. A second possible reason for this discrepancy is that the hygrothermal models used in the simulations and/or the mould models are too conservative.

CONCLUSION

WUFI coupled with mould models are a useful tool for evaluating the moisture-risk of a design solution, though care must be taken when choosing parameters. It is most likely possible to construct moisture safe straw bale outer walls in a Scania climate but to be sure more studies have to be performed. The authors are of the opinion that unventilated outer wall designs are risky and should not be built in a Scania climate. The ventilated designs proved to be less problematic from a mould point of view but not entirely risk free. The third ventilated structure shows good results where only the initial period shows a risk for mould growth. The authors believe that structures built in this manner have the potential to be risk free from mould growth.

REFERENCES

Adapa, P., Tabil, L., Schoenau, G. 2009. *Compaction characteristics of barley,canola, oat and wheat straw*. Saskatoon: Department of Agricultural and Bioresource Engineering, University of Saskatchewan.

Ashour, T. 2003. *The use of renewable agricultural by-Products as building materials*. Egypten: Agricultural Engineering Department, Faculty of Agriculture,Benha University

ASHRAE. (2008). *BSR/ASHRAE Standard 160P, Second Public Review Draft*. Atlanta: American Society of Heating, Refregerating and Air-Conditioning Engineers, Inc.

Bernesson, S., Nilsson, D. 2009. *Halm som bränsle (ISSN 1654-9406)*. Uppsala:Institutionen för energi och teknik, SLU.

Danielewicz, I., Fitz, C., Hofbauer, W., Klatecki, M., Krick, B., Krueger, N., Krus, M., Minke, G., Otto, F., Scharmer, D., Teuber, W. 2008. *Abschlussbericht,Grundlagen zur bauaufsichtlichen Anerkennung der Strohballenbauweise Weiterentwicklung der lasttragenden Konstruktionsart und Optimierung der bauphysikalischen Performance (DBU, Az. 22430)*. Holzkirchen,Kassel, Magdeburg, Oberursel, Sieben Linden.

Deverell, R., Goodhew, S., Griffiths, R., de Wilde, P. 2009. *The noise insulations properties of non-food-crop walling for schools and colleges: A case study*. Nottingham: Design and Built Environment, School of Architecture,Nottingham Trent University

Evrard, A., Louis, A., Biot, B., Dubois, S. 2012. *Moisture Equilibrium in Straw Bale Walls*. Lima: PLEA2012, Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture.

Falk, J. 2010. *Ventilerad luftspalt I yttervägg. Luftomsättningar och konvektiv fukttransport*. Lund: Avdelning för byggnadsmaterial, LTH.

Fraunhofer Institut für Bauphysik 2014. *WUFI (Version 5.2.0.972.DB.24.76)*[Software]. available: http://www.wufi.de/

Hofbauer, W., Krueger, N., Breuer, K., Sedlbauer, K., Schoch, T. 2008. *Mould resistance assessment of building materials – Material specific isopleth-systems for practical application*. Ottawa: Indoor Air 2008, the 11th International Conference on Indoor Air Quality and Climate

Homegrown (No date). *Why build with straw*? http://www.homegrownhome.co.uk/homegrownhomewhystraw.html [2014-03-15]

Hägerstedt, S. O., Harderup, L-E. 2011. *Control of moisture safety design by comparison between calculations and measurements in passive house wallsmade of wood*. Porto: International Conference on Durability of Building Materials and Components

Intertek 2007. *ASTM E 119-05a Fire Tests of Building Construction andMaterials, 2-HR Fire Resistance Test of a Non-Loadbearing Wheat Straw Bale Wall (3098054A)*. Elmendorf, Texas: Intertek Testing Services NA, Inc.

Jeppsson, P, & Ramberg, D 2014, *Simuleringar Av Fukttillståndet I Väggar Isolerade Med Halmbalar : En Studie Av Fukttillståndet I Ventilerade Samt Oventilerade Ytterväggar Isolerade Med Halmbalar I Ett Sydsvenskt Klimat*, Helsingborg : LTH Ingenjörshögskolan vid Campus Helsingborg, Lunds universitet

Johansson, Pernilla (2006). *Mikroorganismer i byggnader. En kunskapsöversikt (2006:22)*. Borås: SP Sveriges Provnings- och Forskningsinstitut.

Kay, J., Anthone, D., Kay, R., Hugly, C. 1990. *Reconnaissance Survey Final Report of Arthur County, Nebraska*. Nebraska: Nebraska State Historical Society.

King, B. 2003. *Load-Bearing Straw Bale Construction. A summary of worldwide testing and experience*. Sausalito: Ecological Building Network.

Künzel, H. 1995. *Simultaneous Heat and Moisture Transport in Building Components. One- and two-dimensional calculation using simple parameters (ISBN 3-8167-4103-7).* Stuttgart Fraunhofer Institute of Building Physics.

Lantbruksnet. 2014. *Price of a straw bale* http://lantbruksnet.se/lantmarknad/sok/allt.php?kid=2&tid=82 [2015-05-12]

Lawrence, M., Heath, A., Walker, P. 2009. *Monitoring of the Moisture Content of Straw Bale Walls*. Berlin: Sustainability in Energy and Buildings: Proceedings of the International Conference in Sustainability in Energy and Buildings (SEB'09).

Magwood, C., Mack, P. 2000. *Straw Bale Building – How to plan, design &build with straw (ISBN: 0-86571-403-7).* Gabriola Island B.C., Canada, New Society Publishers

Mundt-Petersen, S., Wallentén, P., Toratti, T., Heikkinen, J. 2012. *Moisture risk evaluation and determination of required measures to avoid mould damage using the Folos 2D visual mould chart.* Podkylava: Thermophysics 2012- 17th International Meeting of Thermophysical Society, Slovak Republic.

Mundt-Petersen, S.O. 2013. *Moisture Safety in Wood Frame Walls (TVBH-3059)*. Lund: Building Physics, LTH.

Nationalencyklopedin 2014a. *Halmtak*. http://www.ne.se/lang/halmtak/, Nationalencyklopedin [2015-03-04]

Nationalencyklopedin 2014b. *Halm*. http://www.ne.se/lang/halm/, Nationalencyklopedin [2015-03-04]

Nevander, L. E. & Elmarsson, B. 2006. *Fukthandbok. Praktik och teori (ISBN: 9789173331562)*. Stockholm: AB Svensk Byggtjänst

Nilsson, D. 1999. *Analysis and simulation of systems for delivery of fuel straw to district heating plants*. Dissertation. Agraria 205. Swedish University of Agricultural Sciences, Uppsala.

Nilsson, Lars-Olof 2003. *Långtidsmätning av RF och temperatur i konstruktionsdelar i Halmbalshuset-Storkeboda*. Lund.

Pruteanu, M. 2010. *Investigations Regarding the Thermal Conductivity of Straw*. Iaşi: Department of Civil and Industrial Engineering, Technical University of Iaşi.

Sedlbauer, K. 2001. *Prediction of mould fungus formation on the surface of and inside building components*. Stuttgart: Fraunhofer Institute for Building Physics, IBP.

Thelandersson, S., Isaksson, T. (2013). *Mould resistance design (MRD) model for evaluation of risk for microbial growth under varying climate conditions*. Lund: Division of Structural Engineering, Lund University

Viitanen, H 1996. *Factors Affecting The Development Of Mould And Brown Rot Decay In Wooden Material And Wooden Structures: Effect Of Humidity, Temperature And Exposure Time*. Uppsala: Swedish University of Agricultural Sciences, Department of Forest Products

WUFI Forum. 2014. *Material data for straw bale walls*.http://www.wufiforum.com/viewtopic.php?f=3&t=514&p=1822&hilit=straw#p1822 [2014-02-06]

WUFI Wiki. (2014). *Hauptseite*. http://www.wufi-wiki.com/mediawiki/index.php5/Hauptseite