ENHANCED SOURCE AND SINK VENTILATION MODEL FOR WUFI

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ABSTRACT

Ventilation processes in rain screen wall assemblies can be difficult to understand, since the amount of air movement taking place and the effect this has on the construction has several unknowns. Previous work at the Building Research Association of New Zealand (BRANZ) used tracer gas techniques to experimentally establish average ventilation rates in cavity walls. These were found to not only depend on purpose provided ventilation openings, but also on adventitious openings to adjacent cavities in the facade. The measured rates were then applied to models of timber drying experiments undertaken on the same building. These were modelled with good agreement compared to experimental data (McNeil, 2007) using a version of WUFI2D modified to include a source and sink ventilation model. The implementation used in this modified version is identical to what is now found in the commercial releases of WUFI, and allowed a user to model the interaction of outdoor air with air in a cavity.

Recent publications have highlighted possible limitations with the simple source and sink approach to cavity ventilation, with an un-validated COMSOL model showing differences in the modelling of both the wetting and drying phases. There have also been discrepancies noticed in some benchmarking cases that warrant investigation to improve the ability of the model, particularly as the humidity's recorded are high enough to raise durability concerns.

The key assumptions around the vapour and heat transport mechanisms inside air cavities are based on well-known tabulated values. A fundamental limitation in WUFI, is that the moisture storage function does not vary with temperature, which is crucial for relative humidity comparisons to measured data. Understanding these limitations, a more thorough model of the physics in the cavity has been developed which takes into account long wave radiation, and the variation of moisture storage ability of air with temperature. This is done using an interface available in the WUFI kernel for developers. The new model is tested against an experimental case with reasonably good agreement found.

INTRODUCTION

Hygrothermal modelling is becoming an increasingly more useful tool for building scientists, engineers and architects. During the early 2000's BRANZ began working with the Fraunhofer institute for building physics on various aspects of the WUFI range of hygrothermal models as part of the response to a crisis in the New Zealand (NZ) construction industry, the 'leaky building syndrome'. At this time NZ was experiencing widespread external moisture penetration issues in our more modern construction due to a number of systemic failures (Hunn, 2002).The impact on the nation's economy was considerable, and with

the majority of NZ residential building stock being light weight timber framed construction the ongoing risk was high, which understandably led to a strong drive to change the building code. This is not an issue unique to NZ, obvious examples are the leaky condo crisis in Canada (Finch, G., 2007), the same risks are present.

To underpin building code changes and to understand the physical processes that were contributing to the problems experienced, a research programme was undertaken. During the course of this work, several important achievements were made. Ventilation rates in both rain screen and direct fixed construction assemblies were measured using tracer gas techniques (Bassett, M., McNeil, S., 2006), and the drying rates from different locations in wall assemblies were established (McNeil, S., 2007, Bassett, M. 2009). The experimental aspects of this work went hand in hand with hygrothermal modelling of the measurements to enable us to understand the impact that various external climates in NZ could have on any potential solutions.

In order to do this, a source and sink ventilation model which sat inside the WUFI2D calculation kernel was developed (McNeil, 2010). This was then used in subsequent educational tools that have been used to help the NZ industry understand the issues at play (Bassett, M. 2012). It is an identical implementation to the air model which now ships with WUFIPro, and WUFI2D.There has been considerable work in the area of ventilation in rainscreen walls (Karagiozis, A. N. and Künzel, H. M., 2009), (Finch, 2007), (Straube et al, 2004), which highlight how complicated the processes can be. There are also significant ventilation processes that occur in direct fixed walls, and this has recently been investigated by BRANZ (Basset et al., 2015). Figure 2 shows the different airflow processes that take place in a weatherboard timber framed wall common in New Zealand.

Typical NZ Wall Construction:

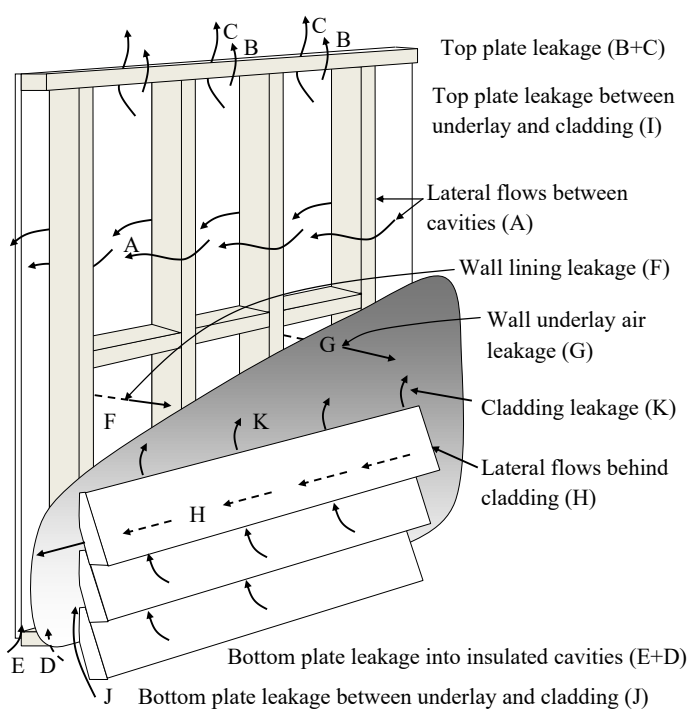

Figure 1: Various air leakage paths in a typical New Zealand wall.

Recent Work

The accuracy and reliability of the initial source and sink ventilation model proved to be very good, particularly when it was used for applications that mirror what it was benchmarked against, which were modelling the drying of wall assemblies. However, a recent project at BRANZ has found difficulty in achieving good agreement between cavity relative humidity levels and those predicted by WUFI (Overton, 2016). The aim of the project was to understand the requirement for controlling vapour movement through lightweight NZ constructions, amid concerns that the risk of accumulation of condensed water between the insulation material and underlay was becoming an issue. An experimental program was undertaken over two years with several varieties of wall construction, including timber and steel frame, with various vapour control measures used.

The measurement specimens used were of typical construction, however, there was particular attention made to build these samples to be airtight, in order to ensure that, as much as is possible that any effects noticed were due to vapour movement, and not air infiltration.

It was found that in most locations in NZ, there was not a great risk of long term accumulation of condensed water between the underlay and insulation, with only short duration condensation events noticed. It did raise an interesting question though, and that was why was the ventilation cavity humidity consistently 'high' in the experimental walls. This would lead to virtually all the measurement walls failing the durability component of ASHRAE 160. A plot of sample data is below (Overton, 2016). Although the sensors recorded 100% RH for a few days, presence of liquid water was only visible with a borescope for short periods.

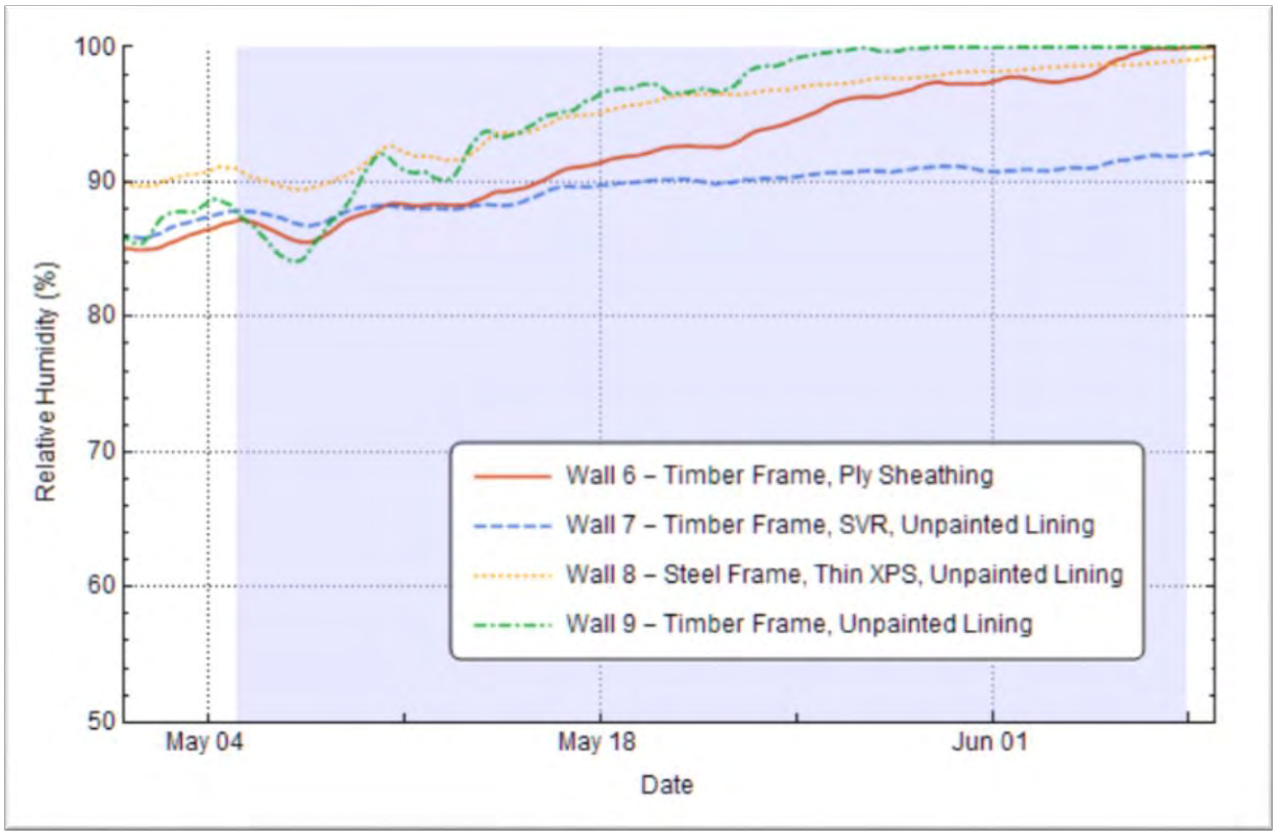

Figure 2: Elevated cavity humidity levels in rainscreen walls during winter in NZ (Overton, 2016)

The findings of (Overton, 2016) and work undertaken in BRANZ in regards to roof moisture in NZ cold roof constructions led to the topic of this paper as a way to enhance the WUFI kernel, and provide further options to simulate ventilation in construction cavities.

Other Approaches to Simulation of Cavity Ventilation

COMSOL Multiphysics has been used by a number of researchers to supplement or replace the capabilities of hygrothermal models like WUFI. COMSOL is a powerful piece of software, though does lend itself more to research use due to the level of mathematical knowledge required to use it effectively.

Several publications (Van Belleghem, M. et al. 2015), (Nespoli, L. et al 2013), have created coupled HAM models, where a COMSOL model of the porous materials is coupled to a CFD model to take care of the air processes. These have shown quite different results from the simplified implementation in WUFI (Van Belleghem et al. 2015), however these comparisons were made directly between the models, ie, not on real data. A comparison of both models to the same measured data would be beneficial.

The use of tools like COMSOL carry with them more effort for the user, in that a material database is not typically available, requiring a degree of extra work to set up a simulation. In addition, issues such as numerical stability have been highlighted.

BRANZ is currently looking at ways to use COMSOL to supplement its use of WUFI in certain situations, with a project underway at present, the main advantage of this will the ability to understand the air movement in detail, for this paper though we are looking at a 1 dimensional model, where a simple source and sink approach should suffice.

Methodology, Ventilation Module Revision:

Notwithstanding the work above, the capabilities of WUFI are well tested and documented across the globe and there is opportunity to provide for a more complete treatment of ventilation for situations where extra accuracy is desired. This can be done without the complexity of a full CFD treatment of cavity air. The rest of this paper details a procedure undertaken to accomplish this.

The current ventilation model deposits the ventilation air at the location the user specifies, with no concern for the path it takes to get there, the same approach is taken here as we are using a simple 1D model, future work (particularly the current COMSOL based project) may enable progress to be made in this area at a later date.

With this in mind, the key to creating a more complete model of cavity ventilation processes, by enhancing the existing source and sink model, was to understand the limitations with the current system.

Since WUFI has evolved from a model for porous materials, it understandably has to treat air movement and its properties in a simplified manner. This currently takes the form of empirical material properties including transport coefficients and storage of heat and moisture. These are based on well tested standards/publications, which focus on energy transport. This does mean however, that the temperature dependence of the moisture storage capacity of air is not implemented, mainly due to the fact that

temperature dependence of the storage capacity of most building materials is insignificant (Künzel, 1995), another reason is that it presents a challenge from the numerical perspective.

From the point of view of the needs of many WUFI users these assumptions are perfectly adequate. The impact on total moisture and heat movement across the wall is likely to be only impacted to a small extent, evident in the number of benchmarking cases that have shown good agreement.

In practice though, if one is interested in what the cavity humidity is with more certainty, the variable moisture storage capacity of air with temperature should be considered as the strong temperature dependence of this can impact on the model. This was evident during the experiments and modeling completed during the BRANZ vapour control in walls project (Overton, 2016).

Another area where the current model could be causing limitations is the treatment of heat transport across the cavity as a lumped conduction term, including longwave radiation. Radiation is the dominant transport process in ventilated cavity walls, so the decision was made to introduce a simple long wave model as a separate transport term. Although long wave radiation flows are reasonably balanced as the temperature differences of the surfaces are within a few tens of degrees at the extremes, it is important to separate if from conduction and convection, since the air temperature is not directly affected by this radiation.

Separating convective and conductive heat transfer coefficients is a possible future improvement, but at this stage will be left until the conclusion of the current COMSOL project. For now tabled data is used. It also makes much more sense to implement this in WUFI2D, not the 1D model we are using here.

Coupling WUFI Models:

There are numerical difficulties in addressing the above inside the WUFI kernel itself, because of the underlying assumptions in the equation system. For this reason an approach where coupling two individual WUFI models together, via a simplified air transport model has been undertaken. This involved dividing the construction into two different domains, with a new domain, representing the cavity inserted in between. The wall construction is shown in figure 3 below, the cladding itself is one WUFI model, while the wall underlay, insulation, and interior lining form the second WUFI model.

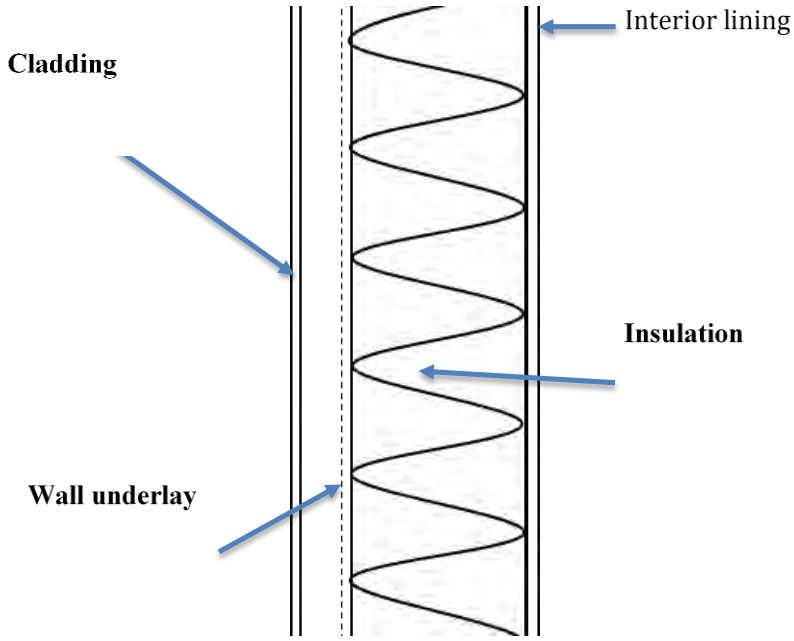

Figure 3: Typical cavity wall construction

This is made possible due to the team at FIBP creating an external sources library that has been made available to BRANZ and other research partners (internal specification document). This library exposes a host of internal routines to developers, which can then be controlled with an external programming language (in this case Java was used). The parameters used for this work are listed in table 1 below.

Table 1: Parameters available for coupling from the WUFI kernel

Exposed Parameter	Unit
Temperature	**°C**
Relative Humidity	**[-]**
Heat flux	**[W/m2]**
Enthalpy flux (including latent heat and radiation)	**[W/m2]**
Moisture Diffusion	**[kg/m2s]**

Wolfram Mathematica® is then used to control all three models (figure 4). It takes all the material data, grid, and other information needed by each copy of the WUFI® kernel from files generated in the standard GUI. There is a small penalty paid for using Mathematica as an intermediary (of the order of 20-30%) however the convenience and ease of interfacing Mathematica with our data acquisition systems made this penalty more than worth it.

All surface parameters, boundary conditions, ventilation rates etc are able to be varied on a timestep by timestep basis inside Mathematica. Long wave radiation is enabled on the surfaces internal to the cavity for each of the WUFI models.

The cavity model coupling the two instances of WUFI is a simple nodal model (Cunningham, M., 1990), which takes its boundary conditions and surface fluxes of both heat and moisture from the two instances of WUFI.

Standard terms, were used to describe the heat and moisture flows due to diffusion and conduction across the boundaries (Künzel, 1995). Tabulated values for interface coefficients literature were used, these are

listed below in table 2.

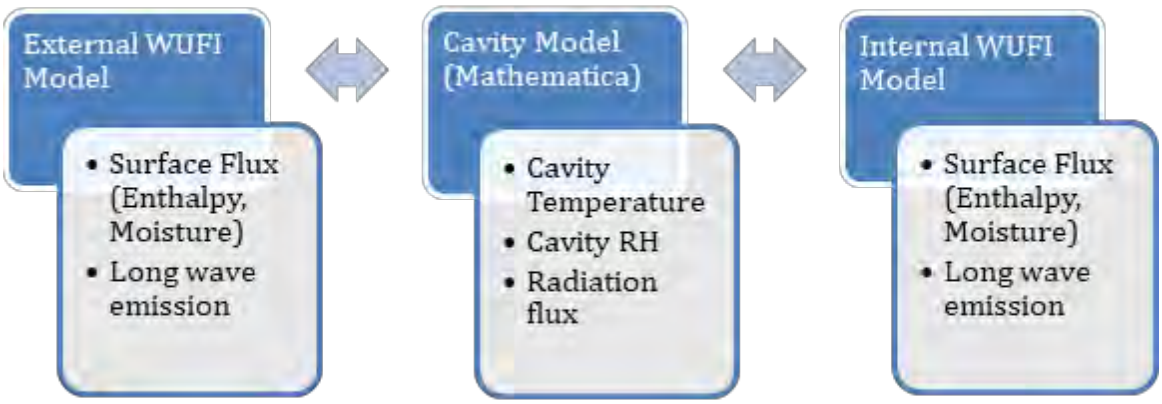

Figure 4: Schematic of model coupling

Table 2: Boundary surface coefficients

Boundary	Coefficient
Exterior heat transfer	10.68 [W/m^{2}K]
Long wave emissivity (ext)	0.18
Short wave absorption (ext)	0.75
Cavity surface heat transfer	8 [W/m^{2}K]
Interior heat transfer	8 [W/m^{2}K]

Long wave radiation between surfaces was calculated using formula 1. Since WUFI calculates the longwave emission using the supplied boundary conditions (ie it assumes radiation into the sky) and we are dealing with an enclosed cavity, a correction was needed. The long wave emission was calculated using the temperature of the surface (and emissivity supplied to WUFI), and was offset against the value calculated with formula 1. As we are assuming parallel plates, a view factor correction has been disregarded.

$$q_{rad} = \sigma(T_L^4 - T_R^4)\frac{1}{\frac{1}{\varepsilon_L}+\frac{1}{\varepsilon_R}-1} \qquad (1)$$

Where

q_{rad}	[W/m^2]:	Heat flow due to long wave radiation
σ	[W/m^2/K^4]:	Stefan Boltzmann constant
$T_{L,R}$	[K]:	Temperature of left and right side of cavity
$\varepsilon_{L,R}$	[-]:	Emissivity of left and right side of cavity

Ventilation source and sink terms were calculated with an identical method to (McNeil, 2007), with a slight modification for a 1D application, as below.

$$X = RH.\frac{P_{sat(T)}}{R_w.T} \qquad [\text{kg/m}^3] \qquad (2)$$

$$Q_m = \frac{ACH}{3600} \cdot d_{cav} \cdot (X_{out} - X_{cav}) \qquad [kg/m^2 s] \qquad (3)$$

$$Q_t = \rho_{out}.\frac{ACH}{3600}.d_{cav}.C_{p,Air}.(T_{out} - T_{cav}) \quad [W/m^2] \qquad (4)$$

Where:

$\boldsymbol{X}$	[kg/m^3]:	Absolute humidity
$\boldsymbol{RH}$	[-]:	Relative humidity
$\mathbf{P_{sat(T)}}$	[Pa]:	Saturation vapour pressure at temperature T
$\boldsymbol{T}$	[K]:	Temperature
$\boldsymbol{R_w}$	[J/kg/K]:	Ideal Gas constant
$\mathbf{Q}_m$	[kg/m^{2}s]:	Moisture source
$\mathbf{Q_t}$	[W/m^2]:	Heat source
$\boldsymbol{ACH}$	[1/h]:	Air change rate
$\mathbf{d}_{cav}$	[m]:	Cavity depth
$\boldsymbol{\rho_{out}}$	[kg/m^3]:	Air density
$\mathbf{C_{p,air}}$	[J/kg/K]:	Heat capacity

Equations 2-4 were implemented inside the nodal model. The air moisture content was calculated using a standard saturation vapour pressure equation, and importantly, this was kept as a temperature dependent term. After applying the equations above a new cavity temperature and RH are then calculated.

As stated above, the interaction of the ventilation air with the surfaces of the cavity enroute to where it has been deposited has been ignored, the same as a conventional cavity air model in WUFI.

RESULTS

A test case has been constructed as per table 3 below. The exterior cladding was contained in one WUFI model, while the SBPO, insulation and interior lining were contained in the second WUFI model.

Boundary condition data was taken from the measurements made in (Overton, 2016) and applied to this model. The ventilation rate was assumed to be a constant 15 ACH, as it was a conservative estimate based on field measurements using tracer gas techniques on the same building.

Table 3: Test case construction materials

	Material	Thickness
Exterior Cladding	Fibre Cement board	7mm
Ventilation Cavity	20mm	
Underlay	SBPO	1mm (WUFI inserted thickness)
Insulation	R1.8 M2K/W Fiberglass batts	90mm
Interior lining	Paper faced Gypsum board	9.5mm

Results of the cavity RH, in comparison with measured values are presented in figures 5 and 6 below for the enhanced and standard models respectively.

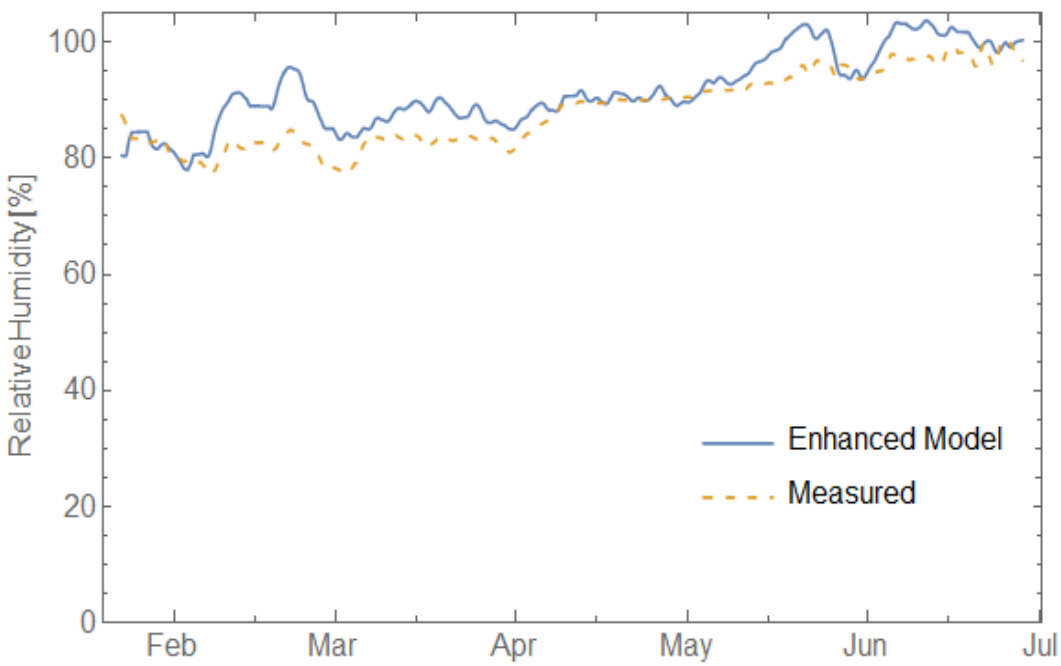

Figure 5: Modelled cavity relative humidity with revised ventilation model

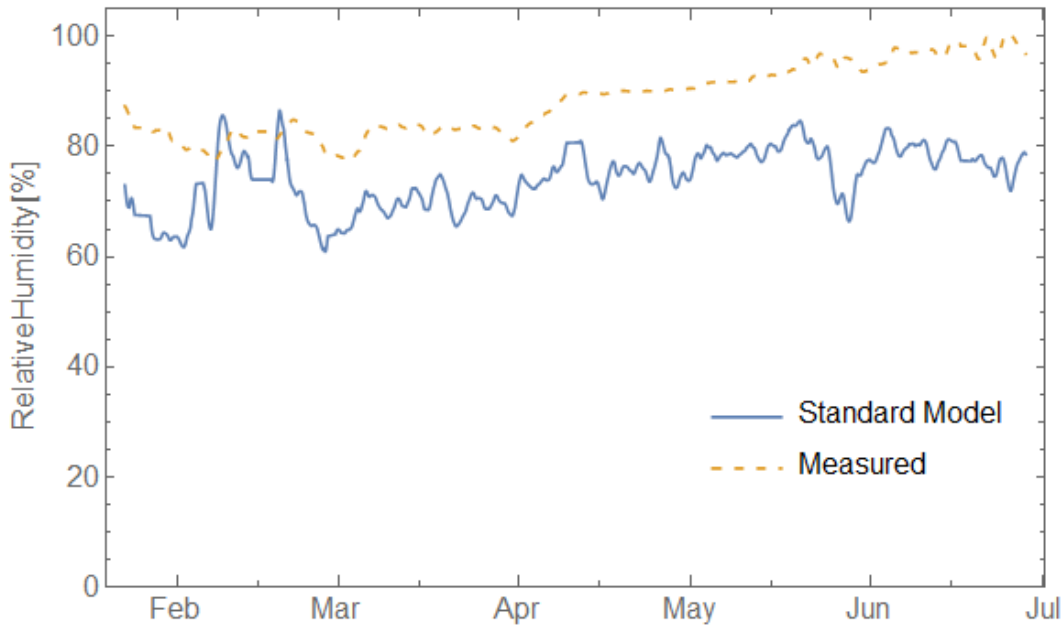

Figure 6: Modelled cavity relative humidity with standard model

Results of the cavity temperatures, in comparison with measured values are presented in figures 7 and 8 below for the enhanced and standard models respectively

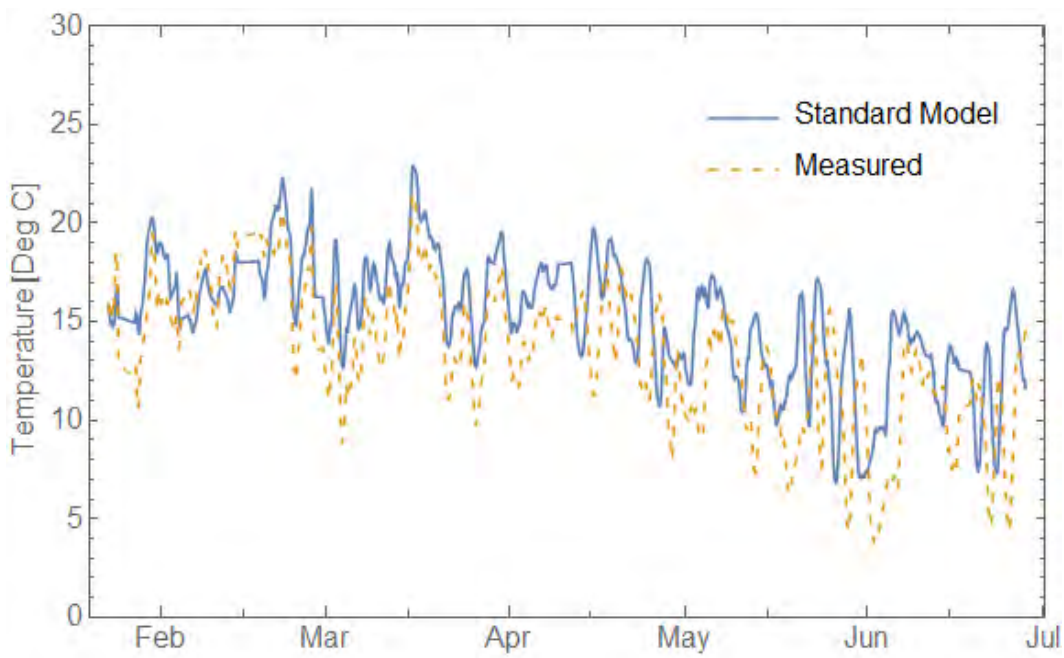

Figure 7: Modelled cavity temperature with standard model

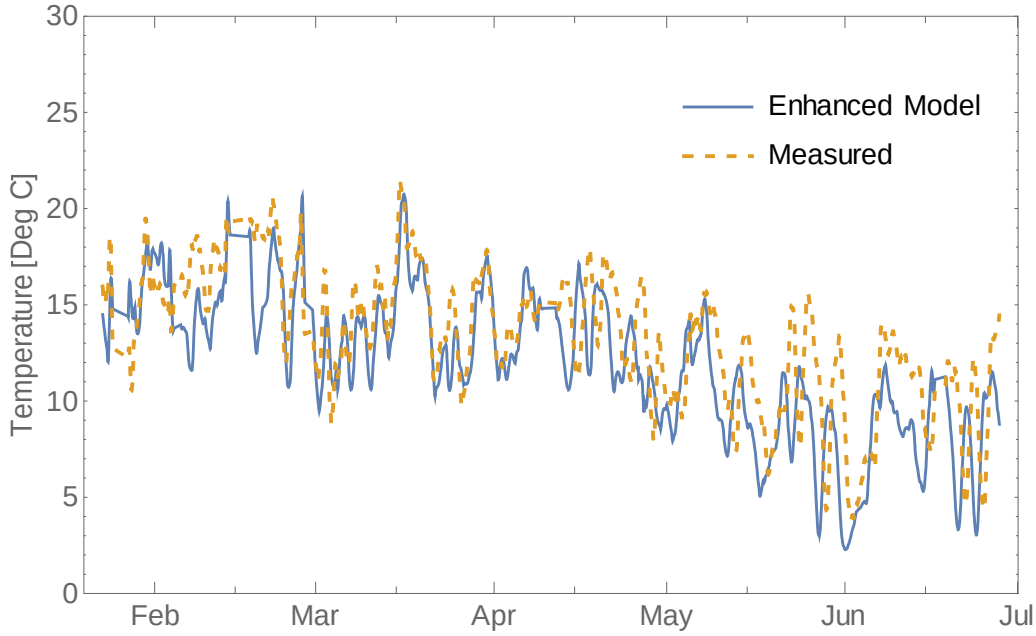

Figure 8: Modelled cavity temperature with revised ventilation model

Figures 9 and 10 below plot the difference between the modelled and measured RH curves from figures 5 and 6 respectively.

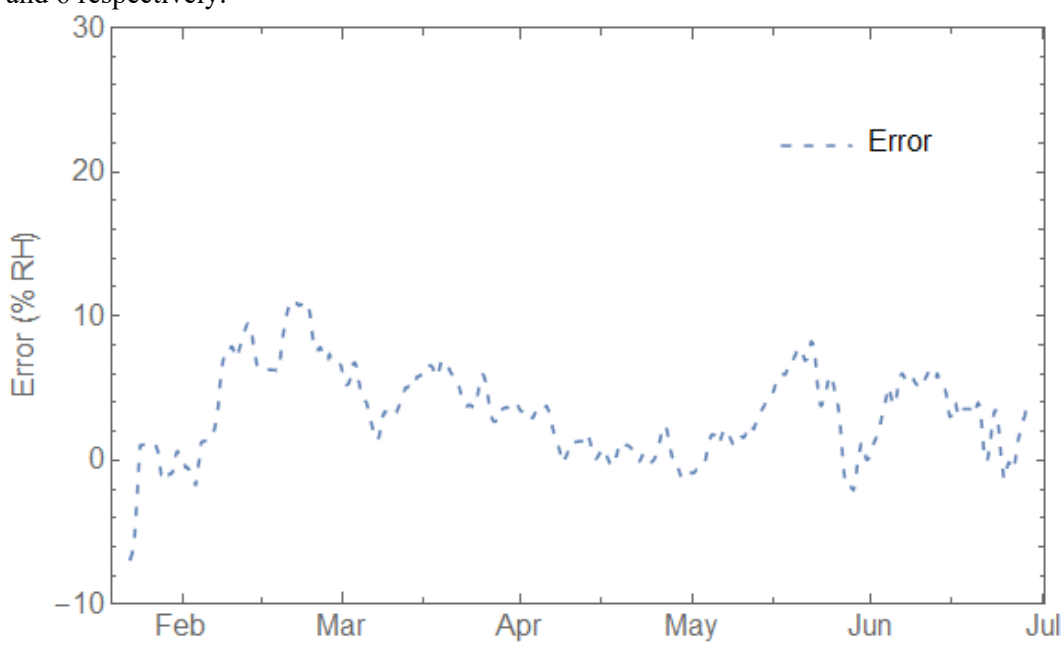

Figure 9: Difference between modelled and measured cavity RH for enhanced model

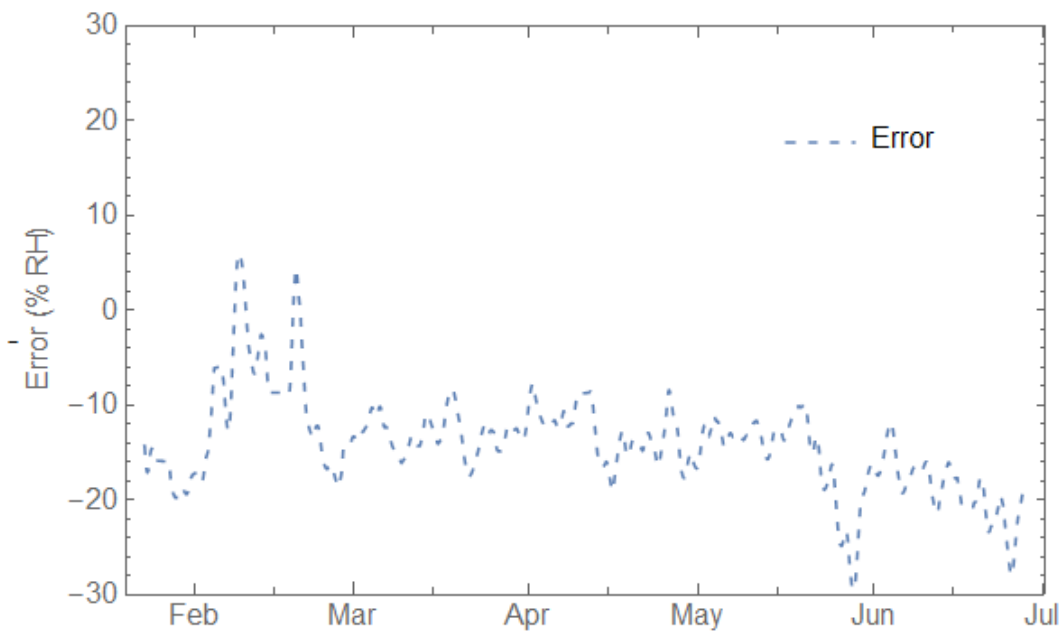

Figure 10: Difference between modelled and measured cavity RH for enhanced model

DISCUSSION AND CONCLUSION

As seen in Figure 5 the agreement between the measured RH and the modified WUFI model is generally good. There does however tend to be an over estimation of the cavity humidity at several points in the calculation run. There are also issues near the tail end of the run, where the relative humidity is over 100%. Figure 9 shows the difference between the enhanced model and the measured data, at worst there is around a 10% error in the modelled RH, with the average being ~3.4% RH, which considering the accuracy of the Honeywell RH probes used to measure the cavity RH, is very encouraging.

Figure 6 shows the standard model as compared to the same measured data, of particular interest is the strong change in the general behavior of the model, where the cavity relative humidity is underestimated by a reasonable margin (of the order of 15% RH). Looking at figure 10, which shows this difference more closely, the underestimation is ~18.7% RH on average.

Similar comparisons between the modelled temperatures and the measurements in figures 7 and 8 present a different picture. In both cases the temperature agreement if quite reasonable. In the case of the enhanced model, the temperature is slightly under predicted by ~1.4°C on average over the length of the run. In the case of the standard model, the temperature is slightly overestimated by ~ 1.9°C on average.

The results of the modelling above demonstrate that the modifications are doing a reasonably good job of modelling the test case. Treating the radiation and heat conduction through the air separately, along with a temperature dependent moisture storage function for air seem to have made a significant difference in the ability to model cavity humidity accurately. Although the standard moisture storage function for air incorporated in WUFI (at a fixed temperature of approximately 20°C) is a good compromise, the improvements noted here demonstrate some improvement is possible should the temperature of the air vary

to any great extent. For the average user, there is the ability in WUFI to change the sorption curve, which might be useful for some applications.

In terms of other improvements, there is some work still needed to try and resolve the differences near the tail end of the calculation run. First to be considered is an extra node in the model to allow for some liquid condensation to be stored. This has been used in previous BRANZ work looking at condensed water on glass, so should be reasonably straightforward to implement. This should go some way to addressing the issue.

There is also scope to revise the surface transfer coefficients, which at the modelled ventilation rate of 15ACH could be higher than the 8W/m^{2}K used currently, which will affect the heat gain of the cavity.

In addition to this it is ideally worth investigating the sensitivity of the model to the heat transfer coefficients in the cavity, as well as the emissivity of the underlay and back of the cladding. Running the model against several test cases should help with this.

The results of this work are encouraging, and there is likely a method that would be able to implement this model in an additional library file (dll), that WUFI could use directly, negating the need for two WUFI models and third party software to interface them.

ACKNOWLEDGEMENTS

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REFERENCES

Bassett,M., McNeil, S.,2006. Measured ventilation rates in water managed wall cavities. Research in Building Physics and Building Engineering Proceedings of the 3rd International Building Physics Conference

Bassett,M.,Overton,G.&McNeil,S.,2009. Ventilation and evaporation rates in wall cavities in New Zealand,12th Canadian Conference on Building Science & Technology

Bassett, M., McNeil, S., Overton, G., 2012 WALLDRY-NZ: An educational tool for rain loads and ventilation drying in cavity walls. Proceedings of the 5th IBPC (International Building Physics Conference)

Bassett, M., Overton, G. and McNeil, S. 2015. Air infiltration in walls with direct-fixed claddings. Journal of Building Physics, 38(6), 517–530.

Cunningham, M. J. 1990. Modelling of moisture transfer in structures – 1. A description of a finite difference model. Building and environment Vol 25 no 1,

Finch,G.,Straube,J.,2007. Ventilated wall claddings: review, field performance and hygrothermal

modelling, Thermal performance of the exterior envelopes of whole buildings X

Finch,G.,Straube,J.,Hubbs,B.,2007.Hygrothermal performance and drying potential of wood frame rainscreen walls in Vancouver's coastal climate. Proceedings from 11th Canadian Conference on Building Science and Technology

Hunn, D., Bond, I., Kernohan, D. 2002. Report to the overview group on the weathertightness of buildings to the building industry authority.

Karagiozis, A. N. and Künzel, H. M., 2009. The Effect of Air Cavity Convection on the Wetting and Drying Behavior of Wood-Frame Walls Using a Multi-Physics Approach, Journal of ASTM International, Vol. 6, No. 10, 2009, pp. 1-15

Künzel, Hartwig M. "Simultaneous heat and moisture transport in building components." One-and two-dimensional calculation using simple parameters. IRB-Verlag Stuttgart (1995).

McNeil,S.,Bassett,M.,2007. Moisture recovery rates for walls in temperate climates, 11th Canadian Conference on Building Science and Technology

McNeil,S., & Bassett,M, 2009, Drying from framing in water-managed walls. Proceedings of the Fourth International Building Physics Conference, Istanbul, Turkey

McNeil,S., & Bassett, M., 2009. Drying of insulated and water-managed wall cavities. Proceedings of the Fourth International Building Physics Conference, Istanbul, Turkey

McNeil,S.,Bassett,M.,Overton,G. & Kehrer,M.,2010 Drying rates in timber frame walls with ventilated cavities - modelled and measured. ICBEST 2010, Vancouver. B.C.

Nespoli, L., Janetti, MB, Ochs, F. 2013. Comparing Different Approaches for Moisture Transfer inside Constructions with Air Gaps - COMSOL Conference Rotterdam, 2013

Overton, G.E. 2016. Vapour control in New Zealand walls. Study report, SR344, BRANZ Ltd, Judgeford, New Zealand.

Straube, J., van Straaten, R & Burnett, E.: Field Studies of Ventilation Drying. Proceedings Buildings IX Conference. ASHRAE Atlanta 2004.

Van Belleghem, M., Steeman, M., Janssens, A. and De Paepe, M., 2015. Heat, air and moisture transport modelling in ventilated cavity walls. Journal of Building Physics, 38(4), pp.317-349.