A novel method established to convert Australian climate data for hygrothermal simulation

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Abstract: The correlation between energy efficient buildings and the increased risk of condensation and mould inside residential and non-residential buildings has been known for some time. Since the 1990's transient calculation methods have been developed to initially calculate the flow of heat and moisture. These tools were then improved to calculate risks associated with mould growth, which causes building decay and affects human health. Internationally, frameworks, standards and guidelines are being developed establishing boundaries and requirements to limit too much user interaction with input and output variables. Key input variables include the exterior and interior climates and the physical attributes of construction materials. In 2018, collaborative research between the Germany and Australia identified a lack of suitably formatted Australian climate data for hygrothermal simulation. Parallel research was also exploring matters regarding water vapour diffusion resistivity properties of Australian construction materials and the development of more appropriate interior climate parameters. This article focusses on the development of a novel method, developed in 2019, to convert Australian government sanctioned climate data into a suitable format for transient hygrothermal simulation. The tool became known as AusHygro 1 and included options for including rain data and hourly interior temperature and relative humidity conditions.

Keywords: Condensation, Mould, Hygrothermal simulation, Climate data.

1. Introduction

The process of designing and making buildings that use less energy for heating and cooling, has required greater amounts of insulation and air control within external envelope systems. This process has made the outside skin much cooler in cool climates and much warmer on hot and humid climates. This act has then created significant differences between the interior and exterior skins of conditioned buildings leading to increased occurrences of condensation and mould in Australian buildings. Sadly, this correlation

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has been known for more than a century (ASHVE, 1937; Teesdale, 1937; Rogers, 1938; Babbitt, 1939; CSIRO, 1962; 1970). As it was proven that the design and construction professions did not address this structural and human health affecting matter, many developed nations commenced instigating building regulations since the 1960's (British Standards, 2002; International Organization for Standardization, 2012; Shrubsole *et al.*, 2014; Dewsbury *et al.*, 2016). Whether it be the southern hemisphere being a bit slower, a more temperate climate, or a lessor expectation regarding the presence of mould in buildings, New Zealand and Australia have been slow to implement change (Dewsbury and Law, 2016; Bulic *et al.*, 2019; Nath *et al.*, 2019; Brambilla and Sangiorgio, 2020). The 'leaky buildings' crisis, which includes moisture ingress, and moisture and mould resulting from hygrothermal processes, has by recent estimates, cost the New Zealand economy NZ$46 billion (Howden-Chapman *et al.*, 2005; Moll and van Raamsdonk, 2011; Buckett, 2013; Overton, 2016; Walls, 2016; Dyer, 2019; 2021). The response on New Zealand has been the inclusion of condensation and mould related building regulations since 2006. In Australia, the first regulations, which only applied to Class 1 and Class 2 residential buildings located within National Construction Code climate zones 6, 7 and 8, were introduced in 2019 (ABCB, 2019).

Since 2008, researchers from the University of Tasmania have been expecting similar events to occur in Australia, and have been liaising and discussing hygrothermal, condensation and mould matters with State, Federal government agencies and industry-based research collaborators. In 2013, this included international relationships with UK condensation risk software developers JPA (JPA TL Ltd, 2016). Between 2013 and 2018, the JPA non-transient software had been used to assess condensation risk within Australian floor, external wall and roof systems in the climates of Darwin, Brisbane, Sydney, Melbourne, Launceston, Hobart, Oatlands and Cradle Mountain. This research was performed based on requests from Government and industry-based collaborators. By 2017, it was acknowledged that the non-transient software that had been used for much of this research, was in common regulatory use in the UK, and which met the requirements of ISO13788 (International Organization for Standardization, 2012), was not the best starting point for broader hygrothermal research in Australia. At this time, informal discussions with the developers of the WUFI transient hygrothermal simulation software, the Fraunhofer Institute of Building Physics increased, leading to a long-term collaborative relationship.

The climatic data for the non-transient JPA software only required twelve monthly inputs for temperature and relative humidity. Research conducted in 2015 for the Insulation Council of Australia and New Zealand explored the impacts of selecting twelve monthly mean climatic values, twelve hot year values and twelve cold year values. This variety of input was selected, to obtain a broader condensation risk response for the wall and roof systems analysed in hot and humid, temperate and cool temperate climates. This highlighted the impact that climate data could have on simulation results.

The 2018 shift to the use of the WUFI Pro transient hygrothermal simulation software required the re-examination of climate data and its critical role in hygrothermal simulation. Whereas the non-transient software only required a monthly value for temperature and relative humidity, the transient software required a more comprehensive data set that included hourly values for a full calendar year, namely:

- air temperature
- relative humidity
- barometric pressure
- wind speed

- Wind direction
- Global solar radiation, and
- Diffuse solar radiation.

The research team drew strong analogies between the international development of transient building energy rating (BER) programs and hygrothermal simulation programs. Both originated in the 1950's with simplistic, non-transient, calculation methods that were enhanced progressively until the broad adoption of desktop computers in the 1990's (Frank B. Rowley, 1941; Muncey, 1966; 1969; Ahmad, 1993; Delsante, 1997; Salonvaara *et al.*, 1998; Künzel and Holm, 2000; Crawley *et al.*, 2005; Delsante, 2006). The sudden availability and calculation capacity of desktop computers allowed for single annual mean values, to become monthly mean values and by the late 1990's hourly values for a month, which were soon replaced by hourly values for a calendar year. This change in calculation capacity, not only provided significant simulation results, for both BER and hygrothermal programs, that could be used to inform design but also required much higher quality inputs in terms of climate data, construction material physical properties and internal loads.

It is interesting to consider the development of climate data within the Australian regulatory framework. The Nationwide House Energy Rating Scheme (NatHERS) was established in 1993 (Ballinger and Cassell, 1995). It became an accepted simulation based method to prove attainment of house design heating and cooling energy use in 2003 (ABCB, 2003). This demonstrates there was a ten-year period where the simulation method, climate data, material physical properties and internal loads were debated and refined within the Australian architectural science and government policy spaces. Whereas the National construction Code had eight climate zones, by 2006, NatHERS had 69 nationally agreed climate zones (ABCB, 2006a; 2006b).

This development of the climate data sets for NatHERS highlights the mix of public servants, architectural scientists, engineers, and CSIRO scientists that were engaged to review international methods for climate data selection and the adoption of the best methods of the day, to establish the 69 climate data sets for NatHERS. Data sets that included a full year of hourly values as listed above. Back in 2018, discussions with peers in the North America, United Kingdom and Europe all agreed that the first step forward for Australian hygrothermal research should be the use of the government sanctioned Building Energy rating climate files. This highlighted a few challenges that were resulting from Australia's slow adoption of hygrothermal aspects to the national building regulations. The first, which is still an issue in 2022, is that there are no government sanctioned files for hygrothermal simulation. Secondly, the government sanctioned files for building energy rating, do not include precipitation data, an issue that is not exclusive to Australia. Thirdly, is the use of a building energy rating data set the best method for hygrothermal simulation. Some of these matters, like precipitation data, if data exists, could be added to existing data sets. However, the greater question regarding the suitability of Australian building energy rating climate data sets and what data should be used for hygrothermal simulation requires a deeper exploration of data collection and data selection. These matters aside, there was a need to establish whether Australian external envelope systems were promoting surface and interstitial mould growth, condensation and moisture accumulation. This position was also supported by leading international researchers, who based on their own experiences in North America and Europe, found that building energy rating climate data sets often provided a 'conservative' answer, as the first step down a nation's hygrothermal research journey.

2.1. Establishing climate data parameters

To quantify what climate data was required and what climate data was available initially required an analysis of the data sets available. The two government sanctioned climate data sets that were available in 2018 included the TMY data that was used for Nationwide House Energy Rating Scheme (NatHERS) simulations and the EPW files that had been provided by the Australian Greenhouse Office (AGO) to the United States government for use with the EnergyPlus building energy rating software. The data included within these two data sets is shown in Table 1. This table shows that the EPW files can include many more types of data than the NatHERS TMY files. There are also some notable differences in the values for some data items, like atmospheric pressure which is measured in hPa for TMY and mb for EPW. Table 1 also shows the much smaller data selection that is required for the hygrothermal software's WAC format. It should be noted that the hygrothermal simulation software used in this research (WUFI Pro), could read an EPW climate data input. However, the AGO provided EPW formatted climate data, did not include any precipitation data. Additionally, a preliminary analysis found differences in the values for temperature and solar radiation between the NatHERS TMY and AGO EPW climate data sets. Based on these differences, the next stage of the research was to develop a software tool that could convert and amalgamate the needed data from the NatHERS TMY data format into a WAC formatted climate data file.

2.2. The development of a software tool to extract and reformat data (AusHygro1)

To establish a suitable WAC climate data set required the development of a new software. This was made possible through a Work Integrated Learning program for final year Information and Communication Technology students. The first stage of the research was to consider both informed and less informed capabilities of the likely software users. This required the establishment of various forms of front-end user interfaces and testing these BETA application versions with likely users (house energy rating professionals and academic researchers). This established some significant differences in user skills and knowledge of the House Energy Rating software input libraries, SCRATCH file and output data-sets for zone temperature and energy use. Based on these differences, two climate data selection pathways were established, namely:

- Selection of SCRATCH file – once a SCRATCH was selected, the software selected the appropriate NatHERS TMY file from the software's weather file library, or
- Section of climate file – where the software identified where the NatHERS TMY weather files were, and the user selected the appropriate climate number.

Table 6: Climate data included in TMY, EPW and WAC formats

	TMY (NatHERS) (Delsante, 2006)	EPW (AGO)	WAC (WUFI)
Location	Yes	Header	Header
Year	Yes	Yes	Not applicable
Month	Yes	Yes	Yes
Day	Yes	Yes	Yes
Hour (0-23)	Yes	Yes	Yes
Minute (0-60)	Not applicable	Yes	Not applicable
Flags re data quality	Not applicable	Yes	Not applicable
Air temperature (0.1°C)	Yes	Yes	Yes
Dew point temperature (0.1°C)	Not applicable	Yes	Not applicable
Absolute moisture content (0.1 g/kg)	Yes	Not applicable	Not applicable
Relative humidity (0.0 to 1.0)	Not applicable	Yes	Yes
Atmospheric pressure	Yes (hPa)	Yes (mb)	Yes (hPa)
Extraterrestrial horizontal radiation (Wh/m^2)	Not applicable	Yes	Not applicable
Extraterrestrial direct normal radiation (Wh/m^2)	Not applicable	Yes	Not applicable
Horizontal infrared radiation from sky (Wh/m^2)	Not applicable	Yes	Not applicable
Wind Speed (0.1m/s)	Yes	Yes	Yes
Wind Direction	Yes (0-16; 0 = calm, 1 = NNE, 16 = N	Yes (Degrees)	Yes
Total cloud cover (oktas, 0 - 8)	Yes	Yes	Not applicable
Flags re data quality	Yes	Not applicable	Not applicable
Global solar radiation on a horizontal plane (Wh/m^2)	Yes	Yes	Not applicable
Diffuse solar radiation on a horizontal plane (Wh/m^2)	Yes	Yes	Not applicable
Normal direct solar radiation on a plane normal to the beam (Wh/m^2)	Yes	Yes	Yes
Global horizontal illuminance (Lux)	Not applicable	Yes	Not applicable
Direct normal illuminance (Lux)	Not applicable	Yes	Not applicable
Diffuse horizontal illuminance (Lux)	Not applicable	Yes	Not applicable
Zenith Luminance (Cd/m^2)	Not applicable	Yes	Not applicable
Solar Altitude (0 to 90)	Yes	Data in header	Not applicable
Solar Azimuth (0 to 360)	Yes	Data in header	Not applicable
Flags re data quality	Yes	Yes	Not applicable
Year data (19, 20)	Yes	Not applicable	Not applicable
Blank	Yes	Not applicable	Not applicable
Opaque sky cover	Not applicable	Yes	Not applicable
Visibility	Not applicable	Yes	Not applicable
Ceiling height	Not applicable	Yes	Not applicable
Present weather observation	Not applicable	Yes	Not applicable
Present weather codes	Not applicable	Yes	Not applicable
Precipitable Water (mm)	Not applicable	Yes	Yes (Ltr/m^2h)
Aerosol Optical Depth (0.001)	Not applicable	Yes	Not applicable
Snow Depth (cm)	Not applicable	Yes	Not applicable
Days since last snowfall	Not applicable	Yes	Not applicable

This first stage then converted the Month, Day, Hour, Air temperature, Atmospheric pressure, wind speed, wind direction and Normal direct solar radiation into columns data suitable as a WAC file. The data for absolute moisture content was required to be converted to relative humidity for the WAC file. A formula was provided by the CSIRO. A selection of data was converted. A selection of the converted relative humidity data was provided to the CSIRO and Fraunhofer Institute of Building Physics researchers who confirmed the quality of the converted data. This conversion method was then included in the overall data reformatting process. This allowed for the climate data from the NatHERS TMY file to provide all the data required, except for precipitation data.

Precipitation data was obtained from the Bureau of Meteorology (BOM). In many cases this data may have been a single value for a twenty-four-hour period. This required the team to average the rain data based on cloud cover and relative humidity. The cloud cover data in the NatHERS TMY file identified when the sky had 100% cloud cover. At time like this, rain could occur. This was then cross matched with relative humidity data. Periods of correlating 100% cloud cover with relative humidity conditions above 90% were selected as the likely times of precipitation. Corresponding precipitation data from BOM was then averaged over these occurrences. The combination of these three processes established a WAC file for the Hygrothermal simulation using the WUFI Pro Software.

2.3. Hygrothermal simulations using EPW, NatHERS TMY and NatHERS TMY + Precipitation

To establish if there was any discernable difference in hygrothermal and bio-hygrothermal simulation results a series of residential external wall system simulations were completed using the WUFI Pro and WUFI VTT software. The WUFI Pro software was used for the hygrothermal simulation, which would calculate the flow of heat and moisture through the external wall system (Schwab, 2021). This would provide hourly temperature and moisture conditions through the wall system for a period of ten years. The WUFI VTT software uses the hourly hygrothermal simulation results to calculate mould growth risk (Viitanen *et al.*, 2015). The mould growth risk simulation applies the mould growth index (MI) developed by Hukka & Viitanen (1999). Internationally, a mould index of 3.0 or more is regarded as undesirable on surfaces or interstitially in external envelope systems (ASHRAE, 2016; AIRAH, 2020; Deutsches Institut Fur Normung E.V. (German National Standard), 2020). This undesirability is based on the international medical acceptance that any presence of visible mould will affect human health (WHO Regional Office for Europe, 2009; Nath *et al.*, 2019). A mould index of nil or 1.0 generally indicates a wall system is safe to construct. A mould index of 1.0 to <3.0 refers to microscopic mould growth, and normally indicates that the wall system should be further investigated, as small differences between the simulation inputs and the wall construction may lead to significant mould growth problems. A mould index of 3.0 of more refers to optically visible mould, and this type of wall should not be constructed.

3. Results

The results discussed here focus on some challenges regarding the establishment of the WAC climate data sets and the results from the hygrothermal and bio-hygrothermal simulations.

3.1. EPW and WAC Climate data

As discussed in the method section, differences were identified in the temperature and other data categories between what was in the NatHERS TMY data and the EPW climate data sets for the same locations. These differences would and did provide different hygrothermal simulation results. For time reasons and the need to focus on the conversion of the NatHERS TMY data, the effect of these differences was not pursued further. Future research must evaluate these differences. Both the NatHERS TMY and AGO EPW climate data sets do not include precipitation data. The method described above to 'average' the precipitation data does not consider rain intensity. This may be a critical matter, as research has identified the need to critically understand wind driven rain and its impact on inward and outward moisture flows within external wall systems (Overton, 2016; Ge *et al.*, 2021; Kuenzel and Dewsbury, 2022). This aspect requires further refinement but may be significantly challenged by data available from the Australian Bureau of Meteorology.

3.2. Hygrothermal and bio-hygrothermal simulations

Figure 1 below shows an example of the hygrothermal and bio-hygrothermal simulation results for the outer portion of the insulation layer in a 7 Star brick veneer wall system in a western orientation. The top graph shows the temperature (red), relative humidity (green) and moisture (blue). The bottom graph shows the mould growth index. In this scenario, the MI is greater than 3.0 in the second year, indicating that this wall is likely to promote mould growth and should not be constructed in this manner within the simulated climate. This simulation was completed using the AGO EPW climate data.

Figure 2 below shows an example of the hygrothermal and bio-hygrothermal simulation results for the outer portion of the insulation layer in a 7 Star brick veneer wall system in a western orientation. The top graph shows the temperature (red), relative humidity (green0 and moisture (blue). The bottom graph shows the mould growth index. In this scenario, the MI may exceed 3.0 in the eleventh year, indicating that this wall requires further investigation. This simulation was completed using the NatHERS TMY data converted to a WUFI WAC file with precipitation data added.

In this wall system, bio-hygrothermally simulated using the AGO EPW climate data showed a mould growth index of 3.0 or more on the interior surface of the clay brick, interior and exterior surfaces of the pliable building membrane and in the outer layer of the wall batt insulation. However, this same wall system, bio-hygrothermally simulated using the converted NatHERS TMY climate data showed a mould growth index of <3.0 in only the outer layer of the wall batt insulation.

Figure 6: Hygrothermal and bio-hygrothermal results of 7 Star brick veneer wall with a western orientation (AGO EPW data)

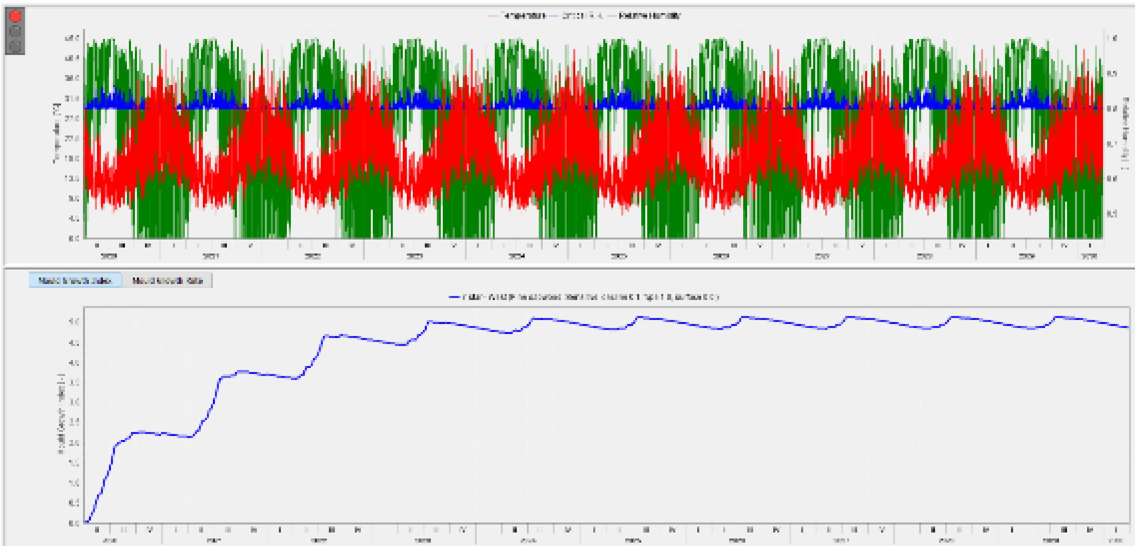
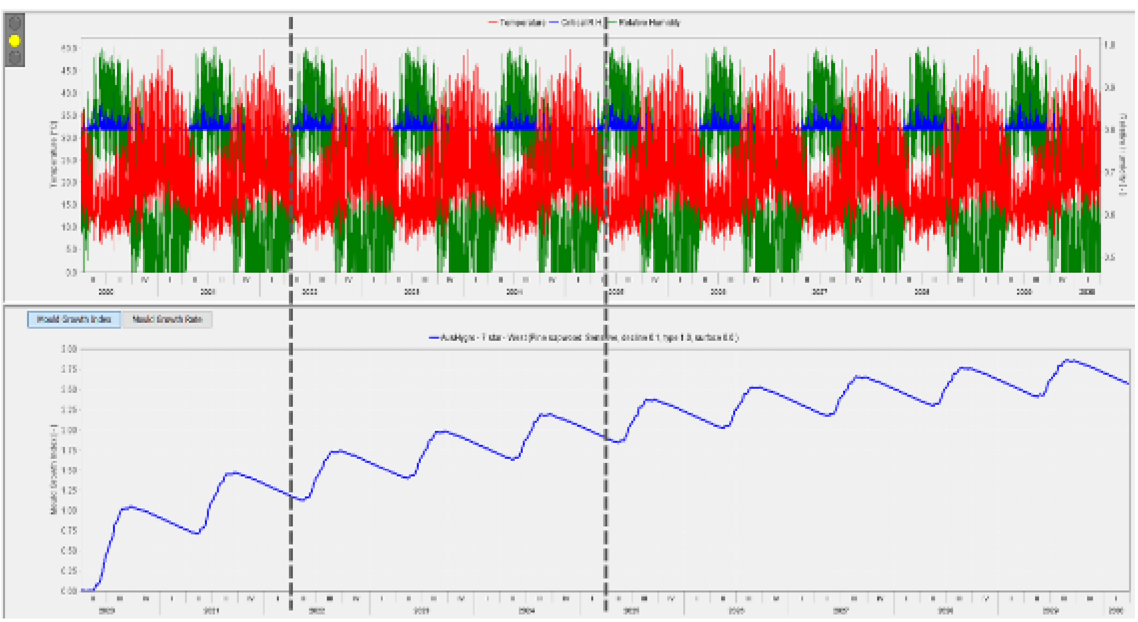


Figure 7: Hygrothermal and bio-hygrothermal results of 7 Star brick veneer wall with a western orientation (NatHERS TMY converted file, with rain data)



4. Discussion

The research involved the development of a computer program, (AusHygro1), which was used to convert NatHERS TMY data into a WAC climate data format for use in by the WUFI suite of hygrothermal simulation programs. The process also included adding precipitation data, which is not present in either the NatHERS TMY or the AGO EPW climate data sets. The aspect of climate data selection plays a critical role in hygrothermal simulation. This research has identified differences in climate data sets provided by the Australian government for use in Building Energy Rating simulations and how these differences provide significantly different results from a hygrothermal and bio-hygrothermal simulation. The differences are significant, as the simulation results shown in Figure 1, would deem this construction system climatically unsuitable, whilst the climate data used for the simulation results shown in Figure 2, might allow for this wall system to be constructed. The differences identified in this research are from two government sanctioned forms of climate data. At this stage, there is no regulation or government-based guidance regarding the selection of climate data for hygrothermal simulation purposes. Based on the experiences of this research, one could ask, what climate data are hygrothermal simulation professionals using to provide guidance to the design and construction professions. Anecdotal evidence from discussions with design professionals using hygrothermal simulation tools includes the use of the last calendar year of data and EPW data from a range of web-based sources. In the case of using data from the last calendar year, a bias would be achieved based on the climatic conditions from that year. The average data sets available in EPW format would remove the bias provided by a single year, but the variety of data sets available would ensure a variety of hygrothermal and bio-hygrothermal simulation results.

Furthermore, recent research by Su (Su *et al.*, 2022) has identified potential risks in the use of climate data sets that have been developed for building energy rating purposes, due to an over-emphasis on air temperature and solar radiation in the data selection process. This process has not recognised the importance of moisture and precipitation and its impact on the wetting and drying processes of external wall systems. Su is exploring this issue as a key component of her doctoral studies.

5. Conclusion

In 2018, this research started to ask the question about what climate data should be used for hygrothermal simulation purposes in Australia. Initial advice from North America and Europe recommended the use of existing government sanctioned Building Energy Rating climate data sets. This research identified differences in the data contained in the NatHERS TMY and AGO EPW climate data sets that are used for Building Energy Rating purposes. These differences led to significant differences in hygrothermal and bio-hygrothermal simulation results. The software developed in this research, AusHygro1, is about to undergo some improvements based on the updated NatHERS climate data that will be released in 2022. This new climate data for simulation purposes will provide yet another version of results. Finally, there is no government- based guidance in Australia regarding which climate data, from which source should be used for hygrothermal simulation purposes. This highlights the need for two very important research and policy actions. There is an urgent need to understand and develop appropriate Australian climate data sets that recognise recent international experiences for hygrothermal simulation purposes. To protect the design and construction professions and building occupants, the building regulators need to specify what data sets a certified design professional should use for hygrothermal and bio-hygrothermal simulation.

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