VARIABILITY OF BUILDING SIMULATION RESULTS DEPENDING ON SELECTED WEATHER FILES AND CONDITIONING SET POINTS – A CASE STUDY FOR A RESIDENTIAL BUILDING IN VICTORIA, AUSTRALIA

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ABSTRACT

Building simulation is a powerful way to evaluate the performance of a building. The quality of simulation results however strongly depends on the accuracy of simulation input data. Especially for weather data files and occupant behaviour it is difficult to obtain accurate data.

This paper evaluates the variability of building simulation results with regards to different weather data sets as well as different heating and cooling set points for a residential building in Victoria, Australia. Thermal comfort according to ASHRAE Standard 55, final energy consumption and peak cooling and heating loads are assessed. Simulations have been performed with EnergyPlus, and weather data for a multi-year approach have been generated with the software Meteonorm. The results show that different weather files for the same location as well as different conditioning set points can influence the results by approximately a factor of 2.

KEYWORDS

weather data, occupant behaviour, heating and cooling set points, residential building, building simulation, energy performance, peak loads, adaptive thermal comfort

INTRODUCTION

Building simulation is a common tool for the evaluation of the performance of a building, especially for new constructions or planned refurbishment, where measurements cannot yet be taken and design measures have to rely on predictions. Depending on the capabilities of the software, very helpful predictions can be derived from simulation results. With sophisticated simulation software such as EnergyPlus, the precision of the results depends on the quality of the input data. Input data can be differentiated into three major categories – the building itself, the behaviour of occupants in the building and the climate. Amongst these

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three categories, the building itself is the most straightforward to model, as dimensions and material specifications are usually available from architectural drawings. In early design stages not all parameters might be specified yet, however all parameters are static in the way that once they are defined they do not change for the lifespan of the building.

For weather files, the situation is more complicated, and the choice of the data set can have significant impact on the results, especially the peak loads (Crawley 1998). In a study focused on commercial buildings and predominantly US climates, Hong, Chang and Lin (2013) found that annual weather variation has greater impact on peak electricity demand than on energy use, and that the weather impact is stronger in colder than in warmer climates and also affected by building size. In a residential context, the comparison of two commercially available weather data sets showed that the resulting annual energy consumption for a residential building in Tennessee/US varied by +-7% and the monthly peak heating and cooling loads by +-40% (Bhandari, Shrestha and New, 2012). In another comparison of the impact of different weather files on commercial buildings in the Netherlands, the authors use the peak cooling load as a measure of robustness of the building (Struck et al., 2009). Important in this context is also the reference time frame of the weather file as most locations are likely to show significant weather variation over a 30 year period (Crawley, 1998). As illustrated by Rahdi (2009) for the climate of Bahrain, past weather data tend to underestimate the electricity consumption by up to 15% and misrepresent cooling loads by up to 10%, whereas more recent files were more accurate. In a study for the climate of Hong Kong, weather files representing future climate change were found to predict an increase in A/C energy consumption by up to 15% in offices and up to 25% in residential flats (Chan, 2011). However, the accuracy of artificial weather data sets for future predictions might be limited, and a study in the UK showed that observed summer temperature performance in an office building in 2006 had been worse than predictions for a hot summer in the year 2050 under a medium high emission scenario (Jentsch, Bahaj, and James, 2008).

This ties in with the resolution of individual parameters in weather files. As pointed out by Barnaby and Crawley (2011), hourly weather files do not reflect real time changes that occur in time steps smaller than 1 hour. Peak differences in individual hourly variables were found to be as high as 90% (Bhandari, Shrestha and New, 2012). While dry bulb and dew point temperature vary relatively slowly with a few degrees per hour, solar radiation and wind can have large and rapid changes over a few minutes, and illuminance data show low accuracy and large uncertainty especially over the short term (Barnaby and Crawley, 2011). In this context Hensen (1999) discusses the potential need for simulations based on weather data with a higher than hourly resolution.

Although potentially important, the micro climate and urban heat island effects are mostly not considered in weather data (Hensen 1999, Barnaby and Crawley, 2011). Especially for future weather files, it has to be considered that different climate parameters can be predicted with different levels of confidence. Higher accuracy can be expected for atmospheric CO2, global mean sea level, global mean temperature, and regional temperatures, whereas changes in climatic variability and climate surprises are likely to be less accurately predicted (Guan, 2009).

With regard to selecting the right weather file for a specific purpose, it is important to consider that not all meteorological variables are of similar importance. The impact of different climatic variables in future weather files on heating and cooling energy requirements in Australian residential buildings was investigated in a study by (Chen, Wang, and Zhengen, 2012). The results show that for heating energy requirements, mean monthly, seasonal or annual air temperatures are the most important parameters, whereas the impacts of changes in the wind speed, solar irradiance, daily maximum/minimum temperatures, humidity, and the time scale were insignificant. For cooling energy predictions the authors recommend a differentiation between climate types. In temperate and hot climates, air temperature and humidity were the most important parameters, on a mean monthly, seasonal and annual basis. In relatively cold climates, air temperature, solar irradiance and humidity are crucial. Alternatively mean monthly air temperature, daily maximum/minimum temperatures and humidity should be used. Ignoring changes in air humidity in future weather files can lead to a 40% difference in cooling energy requirements (Chen, Wang, and Zhengen, 2012). These findings correspond with a study by Struck et al. (2009) which also highlights the air temperature as an important parameter on annual cooling demand.

When selecting weather files, the purpose for which the file has been developed should be considered, i.e. whether it is a typical year, a recent year or designed to comply with a particular building code (Crawley, 1998). Seo, Huang, and Krarti (2009) discuss the difficulty to define how a typical year is characterised, and how this varies for different locations with different amounts of data required to arrive at a definition. Barnaby and Crawley (2011) recommend the identification of predominant weather characteristics at a location, so that the definition of a typical year can be based on this. They also recommend to take the purpose of the study into consideration, as a different file might be suitable for thermal comfort analysis, equipment sizing or energy requirements. Another factor for consideration is the building itself, e.g. a building with a high window to wall ration might be more sensitive to solar radiation, while a small window to wall ratio might react more sensitively to changes in temperature. Also, a naturally ventilated building might be more influenced by wind data than a fully air conditioned building (Hensen, 1999, Struck et al., 2009).

Based on the various considerations with regards to weather files, most recommendations for simulations agree on a multi-year approach. Crawley (1998) recommends the use of three typical files: average, cold/cloudy and hot/sunny. Struck, et al. (2009) tested scenario based multi-year future weather data sets, based on four files, one dedicated to the prediction of annual energy consumption and three to support the overheating risk assessment. Hui and Cheung (1997) also recommend a multi-year approach, e.g. comparing a design weather file with severe climatic conditions for system sizing and a typical year representing average long-term weather conditions for estimating year-round energy consumption.

Besides the modelling of the building and the climate, the behaviour of occupants is the third category of input data which have a significant impact on simulation results. Several studies have attempted to develop methodologies and algorithms that aim for a better representation of occupant behaviour in residential or commercial buildings (Haldi and Robinson, 2009, Andersen et al. 2013, Schweiker et al. 2012, Gunay, O'Brien and Beausoleil-Morrison, 2014, Peng et al., 2012, Hong and Lin 2012, Fabi et al., 2012, Roetzel et al., 2011). Many studies suggest a certain variation of occupant behaviour with lifestyle and context, which can be expressed via different occupant behaviour scenarios. However due to the qualitative/ psychological nature of some influencing parameters the translation of occupant behaviour into a numerical approach is not straightforward.

For this paper a residential building in Victoria, Australia, has been used as a case study. The building has been modelled according to architectural drawings and specifications. The multi–year approach suggested by Crawley (1998) has been used to compare the impact of different weather data sets on adaptive thermal comfort according to ASHRAE Standard 55 (American Society of Heating, Refrigerating and Air Conditioning Engineers, 2010) in free floating condition and on final energy consumption and peak loads in case of heating and cooling. The impact of different weather files has been compared with the impact of different heating and cooling set points as a major parameter of occupant behaviour in Australian residential buildings (Daniel, Soebarto and Williamson, 2015, Nationwide House Energy Rating Scheme, 2014). A more sophisticated modelling of occupant behaviour for this study was not feasible due to a lack of available residential occupancy models for the Australian context. As a first approach though, the use of different heating and cooling settings allows for a ballpark comparison between the impact of weather files and occupants on comfort and energy performance in Australian residential buildings.

METHODOLOGY PART 1: DEVELOPING A MULTI-YEAR APPROACH FOR WEATHER DATA

Measured climate characteristics in the past decade

The case study building is located in Anglesea, a small town southwest of Melbourne, in a climate zone that classifies as temperate without dry season and with warm summer (Cfb) according to the updated Koeppen climate classification (Peel, Finlayson and McMahon, 2007). The closest locations with publicly available weather files in epw file format (EnergyPlus weather data) are Melbourne and Cape Otway both about 110km away from Anglesea. Both locations do not represent the climate of Anglesea very well, the Melbourne climate is significantly warmer and Cape Otway is more exposed.

The nearest weather station with publicly available data (Australian Bureau of Meteorology), Aireys Inlet, is about 17km southwest of Anglesea. The climate in Aireys Inlet is comparable to Anglesea as both locations are part of the same bioregion described as coastal plains, and both locations are covered in the sustainable design guidelines issued by the local council (Parsons Brinckerhoff in conjunction with CH Architects 2009). Daily observations of maximum and minimum temperatures, rainfall and solar exposure are available from the website for the period from 1990 to 2015. As discussed in the introduction, maximum and minimum temperatures are relatively well represented in hourly time steps, future predictions for temperatures come with relatively high levels of confidence, and they have been identified as the most important meteorological parameters with regards to energy requirements in buildings. For this reason, temperature observations for Aireys Inlet have been used to validate the generated data for the location of Anglesea. Observed data for the 10 year period from 2004 to 2013 have been used for this purpose, as the past decade is associated with a significant increase in mean as well as extreme temperatures in Australia (CSIRO, 2015). This period included the 2009 'Black Saturday' heat wave as well as the warmest year on record in 2013. Generated data have been obtained from the software Meteonorm (Meteotest).

Table 1 shows a summary of the daily temperatures measured at the weather station at Aireys Inlet. It compares the number of days where the maximum temperature is above 40, 35 or 30 degrees Celsius, and the minimum night temperature below 10, 5 or zero degrees Celsius. Additionally, it lists the number of days where the minimum night temperature is above 20 degrees, which is the average minimum night temperature during the 2009 Black Saturday Heat wave (Victorian Government Department of Human Services Melbourne, Victoria 2009).

These selected temperature thresholds do not describe the climate comprehensively, but they give an indication of the spread of cold and hot days across the year. They have been selected for their simplicity, as this method can be conducted by building designers without extensive meteorological background and based on freely available data. Given that it is currently not common practice to validate weather data for building simulation, this method can be a first step towards a more comprehensive evaluation and validation of weather data for building simulation.

TABLE 1. Observed exceedance of temperature thresholds for Aireys Inlet for the years 2004 to 2013.

	Measured temperatures for Aireys Inlet											
Number of days / nights with:	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average 2004-2013	Cape Otway EnergyPlus weather data
maximum day temperature >40 degrees C	0	0	2	1	1	**3**	1	0	1	1	**1**	0
maximum day temperature >35 degrees C	7	3	9	8	8	**8**	3	3	6	8	**6**	1
maximum day temperature >30 degrees C	15	23	20	19	16	**18**	12	9	18	21	**17**	7
minimum night temperature <10 degrees C	185	165	192	147	169	**175**	206	160	184	145	**173**	94
minimum night temperature <5 degrees C	11	8	10	14	20	**9**	8	8	12	9	**11**	0
minimum night temperature < 0 degrees C	0	0	0	0	0	**0**	0	0	0	0	**0**	0
minimum night temperature >20 degrees C	2	3	2	3	4	**3**	2	1	6	2	**3**	16

The following conclusions for the measured data within the past decade can be drawn from Table 1:

- The number of days with a maximum temperature >35 degrees C varies between 3 and 9 (factor 3)
- The number of days with a maximum temperature >30 degrees C varies between 9 and 23 (factor 2.5)
- The number of days with a minimum night temperature <10 degrees C varies between 145 and 206 (factor 1.4)
- The number of days with a minimum night temperature <5 degrees C varies between 8 and 20 (factor 2.5)

The second to last column in Table 1 shows the average values for the 10 year period. As can be expected, there are significant deviations between the average year and individual years during this period, which indicates that an average year does not necessarily represent a whole decade very well. However, the average year does show a similar distribution of temperatures with the observations from year 2009, which is in terms of climate is the most memorable year of the past decade in Victoria. For this reason maximum and minimum temperature observations from 2009 have been used to represent the typical weather in the past decade. These data are used for comparison and validation of generated weather data.

The deviations between the EnergyPlus weather data set for Cape Otway (last column in Table 1) and the average of the 10 year period vary between a factor of 2 and a factor of 11. The Cape Otway file significantly underestimates the number of hot days as well as the number of cold days, and it overestimates the number of warm nights. It therefore does not represent the actual spread of temperatures across the year in Anglesea and has not been considered for use in this study.

A generated weather file for the past decade

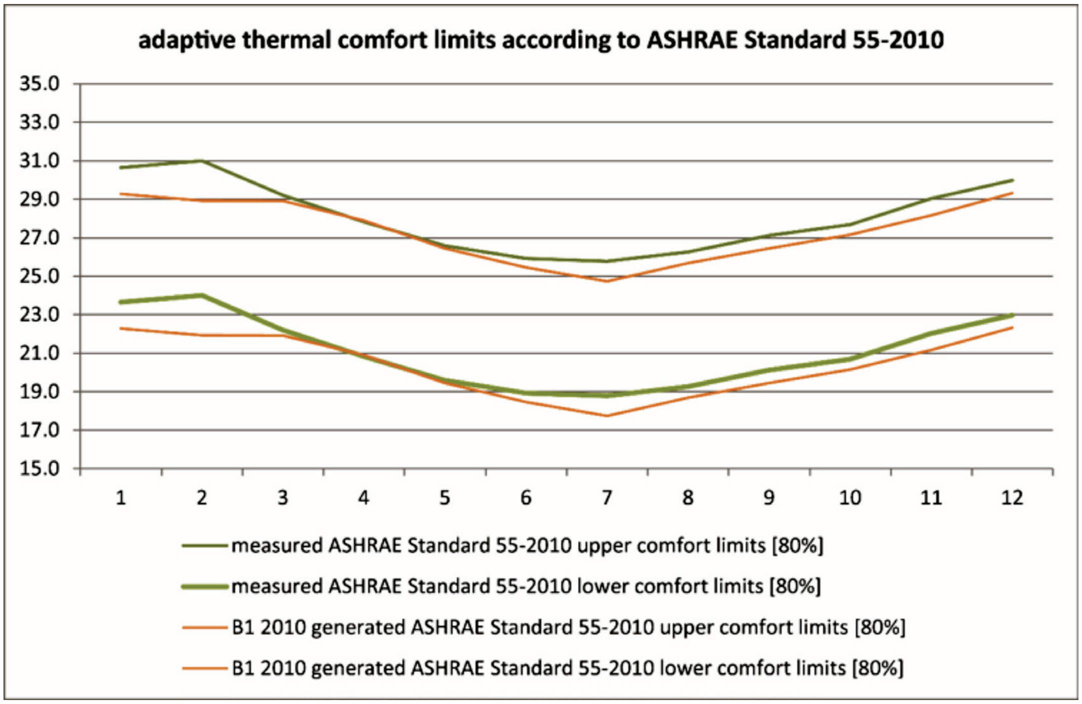
In order to produce a weather file with characteristics similar to the observations for 2009, the software Meteonorm (Meteotest) has been used. This software allows for some adjustments to the weather data sets, e.g. data can be generated based on extreme or average values, and they can be based on different time periods in the past or future climate change scenarios. This allows for the generation of different weather files for the same location, from which one can be selected that matches the observations as closely as possible. Table 2 shows the distribution of temperatures above or below different temperature thresholds for the 2009 weather observations compared with the generated weather file that showed closest similarities. Compared with measurements of 2009, the generated file with closest similarities overestimates the nights with minimum temperatures >= 20 degrees as well as the nights with a minimum temperature of <5 degrees C, but it slightly underestimates the nights below 10 degrees C.

TABLE 2. Distribution of temperatures above or below different temperature thresholds for weather observations from 2009 and generated weather data which show the closest similarities.

	day >40	day >35	day >30	night <10	night <5	Night <0	night >20
Aireys Inlet measured data for 2009	3	8	18	175	9	0	3
Generated data set (closest match to 2009 observations)	3	9	17	168	15	0	13

In order to evaluate the impact of deviation between the observed and the generated data set with regard to their yearly distribution and related adaptive thermal comfort assessment, the adaptive thermal comfort limits for 80% acceptability according to ASHRAE Standard 55 (American Society of Heating, Refrigerating and Air Conditioning Engineers, 2010) are shown in Figure 1. Compared to the measured data, the generated data set underestimates the comfort temperatures by about 1-2 degrees during the summer period in January and February. From March to May the comfort temperatures for both data sets are relatively similar. From June to December the generated data set underestimates the comfort temperatures by about 1 degree.

FIGURE 1: Comparison of the ASHRAE Standard 55 adaptive thermal comfort limits based on the measured vs. the generated weather file for 2009.



Future climate change predictions

In order to evaluate the building's performance in a future climate, simulations have to rely on predictions based on future climate change scenarios. Observations from the past century showed an increase in average maximum temperatures, the number of hot days (above 35 degrees C) and hot nights (above 20 degrees C), as well as a decrease in average minimum temperatures, cold days (below 15 degrees C), and cold nights (below 5 degrees C) (Intergovernmental Panel on Climate Change, 2007).

Predictions of future trends by the IPCC and CSIRO indicate the following changes for the investigated region (Intergovernmental Panel on Climate Change, 2007, CSIRO, 2011). When generating future climate change weather files, these should reflect these predictions.

- Within 800 km of the coast, a mean warming of 0.1 to 1.3°C is likely by the year 2020, relative to 1990, 0.3 to 3.4°C by 2050, and 0.4 to 6.7°C by 2080
- In temperate areas, this translates to 1 to 32 more days/year over 35°C by 2020 and 3 to 84 more by 2050, with 1 to 16 fewer days/year below 0°C by 2020 and 2 to 32 fewer by 2050.
- Potential doubling in the number of days over 35ºC in Melbourne by 2070.
- Number of hot days above 35 degrees C: long term average 1961-1990 (9.9), 2000-2009 average (12.6), 2030 projected (12), 2070 projected low emissions scenario (14), 2070 projected high emissions scenario (20)

A generated future weather file

In the paragraph above, characteristics for climate change in Victoria, Australia, have been discussed and the most important criteria which should be reflected in generated data sets for the future are as follows:

1. Doubling of the number of days per year with temperatures above 35 degrees by 2070
2. A decrease in the number of cold days/a general mean warming

Based on these characteristics, climate change weather files for the year 2070 have been generated with the software Meteonorm. Table 3 compares the number of days when the temperature is above or below different thresholds. The comparison includes the measured weather data for 2009 for Aireys Inlet, and a future weather data set for 2070 for Anglesea which meets the climate change characteristics described above. In comparison to 2009, the future weather file for 2070 shows a significant increase in days with temperatures above 35 degrees C, and a general warming, i.e. increase in days with temperatures above 30 degrees and nights above 20 degrees C as well as a decrease in cold temperatures below 10 and 5 degrees.

As for 2009, it was very difficult to generate a weather file that exactly matches the predictions. However, the generated file for 2070 clearly represents the trends of the climate change predictions for the region. Although further meteorological validation could produce a more accurate file, the generated file is useful for the multi-year approach attempted in this study.

TABLE 3. Number of days with temperatures above or below thresholds for measured weather data 2009 in Aireys Inlet, and a generated data set based on climate change scenario A2 for the year 2070.

	day >40	day >35	day >30	night <10	night <5	Night <0	night >20
Aireys Inlet measured data for 2009	3	8	18	175	9	0	3
Generated data set, IPCC climate change scenario A2, year 2070	5	12	35	107	3	0	20

An extreme winter file

Observations from the past century as well as predictions for the future clearly indicate a general trend in warming for the investigated region, and there is no evidence of predictions for colder temperatures in the future. The use of a weather file representing an extreme winter scenario is therefore not realistic for comfort predictions. However, extreme case scenarios are typically used to size heating and cooling systems. For the purpose of the multi-year approach in this study, a weather file representing the worst case winter scenario has been used for comparison with the 2009 and the future weather data. Table 4 shows the measured data for 2009, as a typical year of the past decade, in comparison with a Meteonorm standard weather file for Anglesea which has a significantly lower number of days with hot temperatures and a larger number of days with cold temperatures. The difference is most significant for the minimum night temperatures. As the generated Meteonorm standard weather file shows, significantly lower temperatures compared to all the measured data sets in Table 1 for the past decade, this file is considered an extreme winter scenario for the purpose of this study.

TABLE 4. Number of days with temperatures above or below different thresholds for measured data 2009, and a weather files representing an extreme winter scenario.

	day >40	day >35	day >30	night <10	night <5	Night <0	night >20
Aireys Inlet measured data for 2009	3	8	18	175	9	0	3
Extreme winter scenario, (Meteonorm standard data)	0	2	11	230	50	0	4

METHODOLOGY PART 2: MODELLING OF THE CASE STUDY BUILDING

The investigated case study building is a 200m^2 two storey residential building in Anglesea, Victoria. It has been selected for this case study because detailed architectural drawings and material specifications were available to the author in order to provide a simulation input reflecting real 'as built' conditions. In addition to that, the building follows passive design principles allowing for natural ventilation in combination with thermal mass and can therefore demonstrate to what degree thermally comfortable conditions can be achieved without additional use of air conditioning. The location of the building also illustrates the difficulty of selection and validation of weather data sets for locations other than major cities.

The building has double brick walls which is a common construction type in Victoria. The internal brick layer as well as the concrete floor are exposed to the building interior providing a significant amount of thermal mass. The ground floor consists of a large double storey living area with integrated kitchen, a bedroom as well as bathroom and laundry, the upper floor in the western half of the building has an additional bedroom and bathroom. The building has a non-rectangular geometry and its open plan layout together with openable windows in all spaces allows for cross ventilation. When natural ventilation is not sufficient to provide thermal comfort, a multi-split air conditioner is assumed to provide additional heating or cooling. North facing windows are shaded by overhangs and trees. The building is used as a second home and assumed to be occupied 5 days a week by three persons.

Two different usage patterns of the heating and cooling system have been compared in this study. Control pattern 1 follows the NatHERS (2012) recommendations assuming a typical heating set point for living spaces of 20 degrees C, and a typical cooling set point of 23 degrees C for climate zone 64 (Cape Otway). Control pattern 2 assumes energy conscious operation of the air conditioning system with a heating set point of 19 degrees C and a cooling set point of 27 degrees C. The heating set point has been determined based on the average lower comfort limits for 80% acceptability according to ASHRAE Standard 55 during the heating period. The cooling set point has been determined based on the average upper comfort limits for 80% acceptability according to ASHRAE Standard 55 during the cooling period (American Society of Heating, Refrigerating and Air Conditioning Engineers, 2010). Table 5 gives an overview of the modelling assumptions for the house.

TABLE 5. Modelling assumptions for the investigated residential building

Envelope	- West façade double brick u=1.2 W/m^2K - All other facades double brick u=0.48 W/m^2K - Timber frame elements u=0.4 W/m^2K at staircase - Roof panels (structural insulated panels) u=0.16 W/m^2K - Ground floor slab u=4.2 W/m^2K
Windows	- Double glazing u= 2.1W/m^2K, SHGC=0.47, Tvis = 0.48
Occupancy	- Monday to Friday: 100% from 8pm to 10am, 60% from 10am to 8pm - Saturday and Sunday: 0% (building assumed to be occupied 5 days a week)
Electric equipment	- 4W/m^2 - Monday to Friday: According to estimates by the architects, 10% minimum usage during the night, peaks of 30% in the morning and 60% in the evening. - Saturday and Sunday: 10% minimum usage for 24h during unoccupied days to account for fridge as well as standby mode
Lighting	- 7W/m^2 - Artificial lighting controlled based on daylight illuminance set point 150lux. - Monday to Friday: during daytime- lighting dimmed to meet illuminance requirements, during night time- lights off - Saturday and Sunday: lights off during absence of occupants - 30% chance that the light is still on when daylight is sufficient, due to inaccuracies of manual light switching
Natural ventilation	- Monday to Friday: 6am to 10pm- max air exchange with cross ventilation = 2 1/h, 10pm to 6am - max air exchange with cross ventilation = 3 1/h (night ventilation). - Saturday and Sunday: Infiltration 0.7 1/h (windows closed for security reasons during absence of occupants)
Conditioning	- Class A multi-split air-conditioner, SCOP 3.7, EER 5.35 - Heating period from April to October. - Cooling period from September to May. - Saturday and Sunday: no heating or cooling during absence of occupants
Conditioning set points	- Control pattern 1 (NatHERS recommendation): Heating set point 20 degrees C and cooling set point 23 degrees C - Control pattern 2 (energy conscious occupants): Heating set point 19 degrees C and cooling set point 27degrees C

RESULTS

Adaptive thermal comfort evaluation (free floating condition)

In the first part of this study the above described building has been evaluated with regard to adaptive thermal comfort according to ASHRAE Standard 55 (American Society of Heating, Refrigerating and Air Conditioning Engineers, 2010). Therefore, the building has been modelled as free floating, without any heating or cooling in operation. This facilitates the assessment of how well the building design and fabric itself is performing.

TABLE 6. Thermal performance of the building without heating and cooling

	Weather data set matching 2009 conditions	Climate change scenario A2, year 2070	Extreme winter scenario
Percentage of occupied time with indoor temperatures within the ASHRAE Standard 55 adaptive thermal comfort limits for 80% acceptability	55	61	49
Percentage of occupied time with indoor temperatures exceeding the ASHRAE Standard 55 upper comfort limits for 80% acceptability	2	3	1
Percentage of occupied time with indoor temperatures exceeding the ASHRAE Standard 55 lower comfort limits for 80% acceptability	43	36	50
Maximum indoor temperature [degrees C]	32.2	32.8	29.1
Max indoor temperature [degrees C] 90 percentile	27.6	28.6	25.5
Max indoor temperature [degrees C] 80 percentile	26.7	27.8	24.6
Minimum indoor temperature [degrees C]	13.4	14.3	12.9

The results are presented in Table 6. It can be observed that the percentage of occupied time when the temperatures in the building are within the boundaries of the ASHRAE Standard 55 adaptive thermal comfort limits for 80% acceptability vary significantly from about 50% for the extreme winter scenario and 55% for the data set matching 2009 conditions to about 60% for climate change scenario A2 in 2070. All three weather data sets are consistent in their prediction that the exceedance of the upper comfort limits is almost negligible (<3%), whereas the majority of exceeding hours is related to exceeding the lower comfort limits (35-50%). This clearly indicates that the building requires additional heating in winter, rather than cooling during summer. As can be expected, the weather file for a future warmer climate results in the highest percentage of comfortable occupied time and the lowest percentage of exceedance of the lower comfort limits. This means that the thermal performance of the building in a free floating condition will improve with climate change.

The maximum indoor temperature for 100, 90 and 80% of the occupied time in the building differs slightly with 32.8 / 28.6 / 27.8 degrees C for the climate change scenario A2 in 2070, 32.2 / 27.6 / 26.7 degrees C for the data set matching 2009 conditions and 29.1 / 25.5 / 24.6 degrees C for the extreme winter scenario. For all three weather files, the temperatures during 90% of the occupied time are below 30 degrees, which indicates that the building does not easily overheat.

It can be observed that compared to the weather data set matching 2009 conditions, the climate change scenario A2 in 2070, results in maximum indoor temperature which are about 1 degree C higher, while for the extreme winter scenario they are about 2-3 degrees C lower.

Figures 2-4 illustrate the distribution of indoor operative temperature over the mean monthly outdoor air temperature according to ASHRAE Standard 55. It can be observed that the mean monthly outdoor air temperature varies significantly for the three weather data sets. For the extreme winter scenario it ranges from about 10 to 18 degrees, for the weather file matching 2009 conditions from about 11 to 20 degrees and for the climate change scenario A2 for 2070, it ranges from about 13 to 22 degrees C. This shows the ideal behind the adaptive model that a warmer year also allows for higher comfort temperatures. For the weather file matching 2009 conditions as well as the A2 climate change scenario for 2070, the mean monthly outdoor temperature is within the applicability range of the adaptive model for all occupied hours. For the extreme winter scenario there is a small number of hours where the mean monthly outdoor air temperature is below the applicability range of the comfort model.

FIGURE 2: ASHRAE Standard 55 adaptive thermal comfort for climate change scenario A2 in 2070

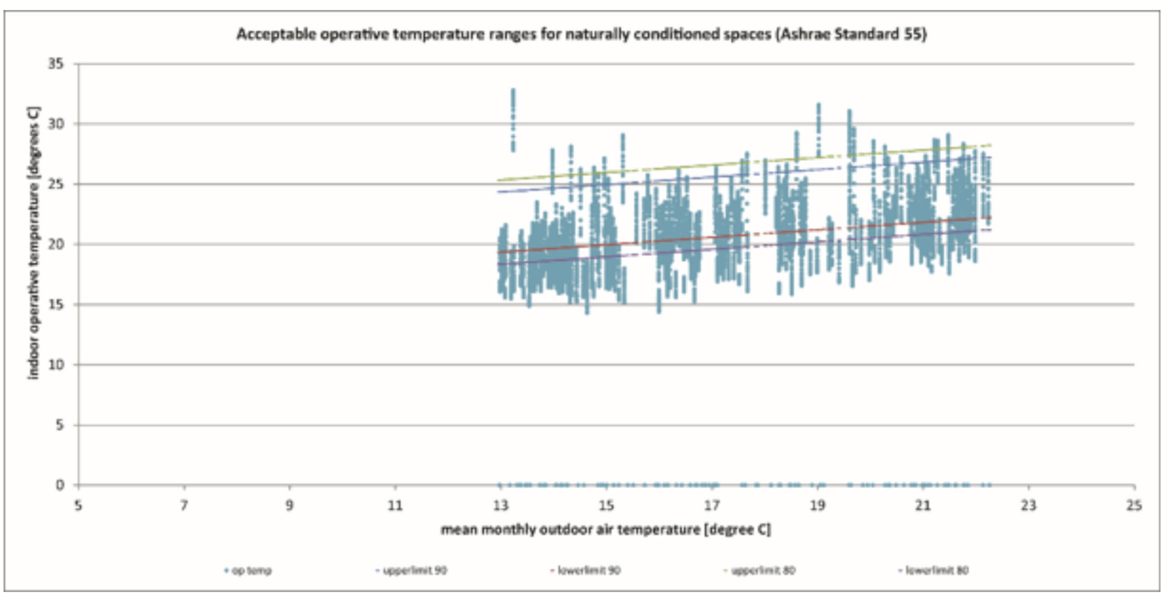


FIGURE 3: ASHRAE Standard 55 adaptive thermal comfort for the weather data set matching 2009 conditions

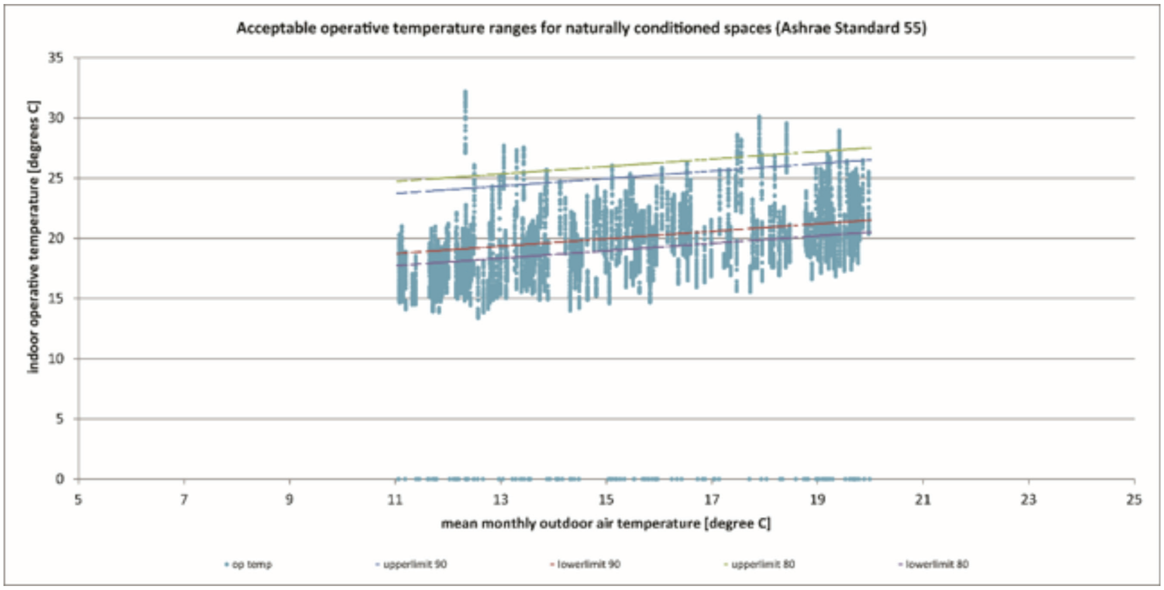
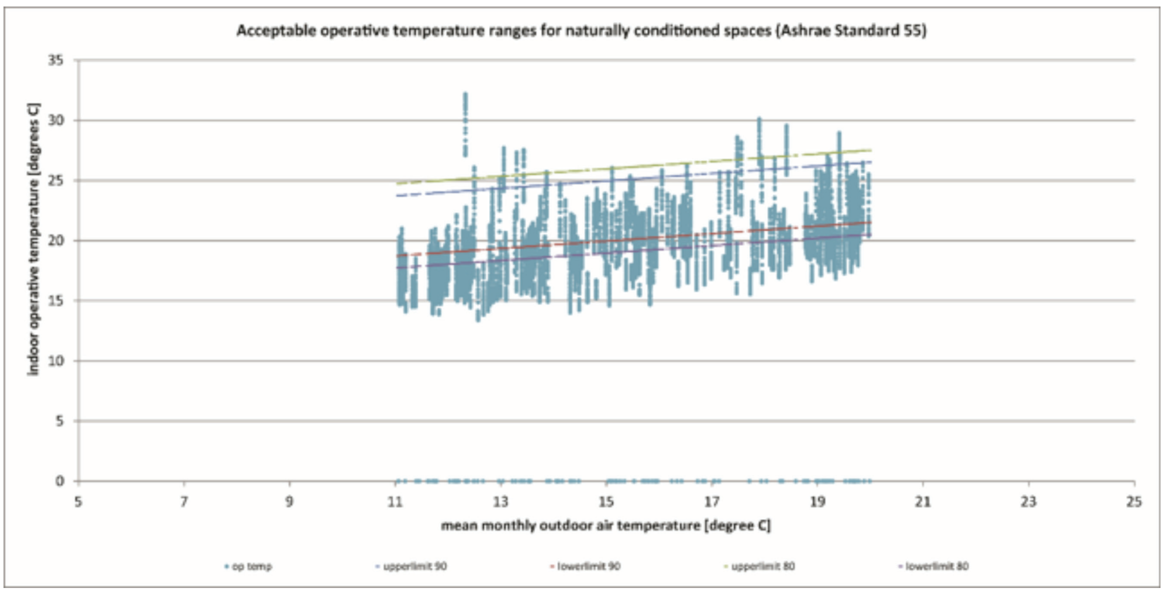


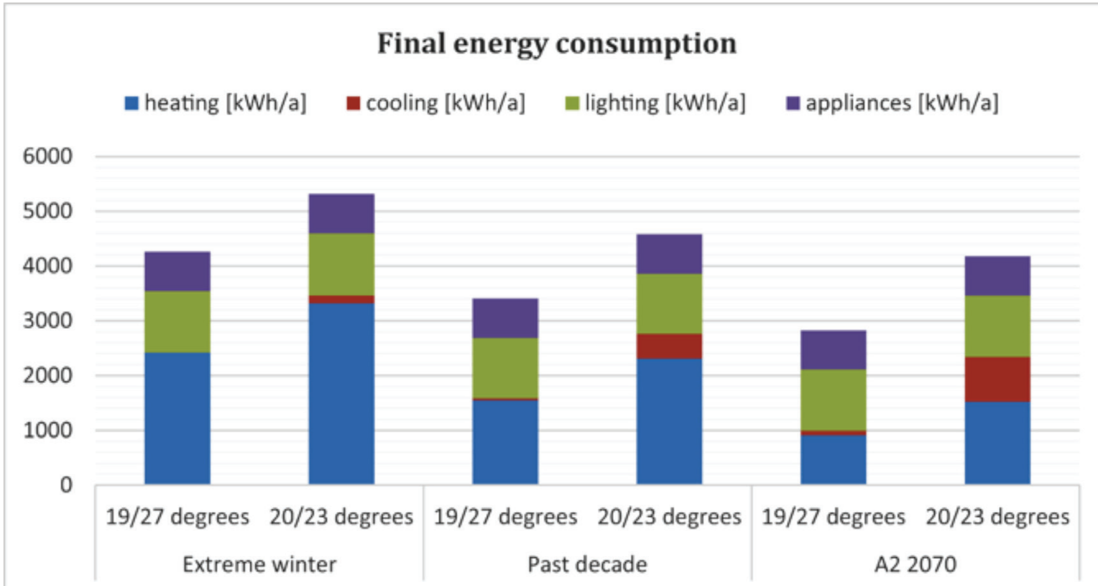
FIGURE 4: ASHRAE Standard 55 adaptive thermal comfort for the extreme winter scenario



Final energy consumption including heating or cooling

Figure 5 illustrates the variability in final energy consumption depending on the weather data set as well as the heating and cooling set points. For all configurations it is obvious that the warmer the climate, the lower the overall final energy consumption. This is predominantly due to a reduction in heating energy consumption. Energy use for appliances is constant for all configurations and the impact on lighting energy consumption is negligible. Cooling energy consumption increases the warmer the weather data, however cooling is the smallest share in the total final energy consumption in most configurations, and the decrease in heating energy is larger than the increase in cooling energy consumption.

FIGURE 5: Variability of final energy consumption depending on weather data set and conditioning control patterns.



The selected weather data set has significant influence on the final energy consumption. For the conditioning control pattern 1 (NatHERS recommendation 20/23 degrees C) and compared with the weather file matching 2009 conditions, the extreme winter scenario increases the final energy consumption by about 15%, whereas the A2 climate change scenario for 2070 reduces the overall energy consumption by about 10%. For control pattern 2 (adaptive set points, 19/27 degrees C), the extreme winter scenario increases the final energy consumption by 25%, whereas the A2 climate change scenario for 2070 reduces the energy consumption by more than 15% compared to the weather file matching 2009 conditions. The impact of the different weather data sets on the variability in final energy consumption is larger (about 40% variability) for control pattern 2 compared to control pattern 1 (about 25% variability).

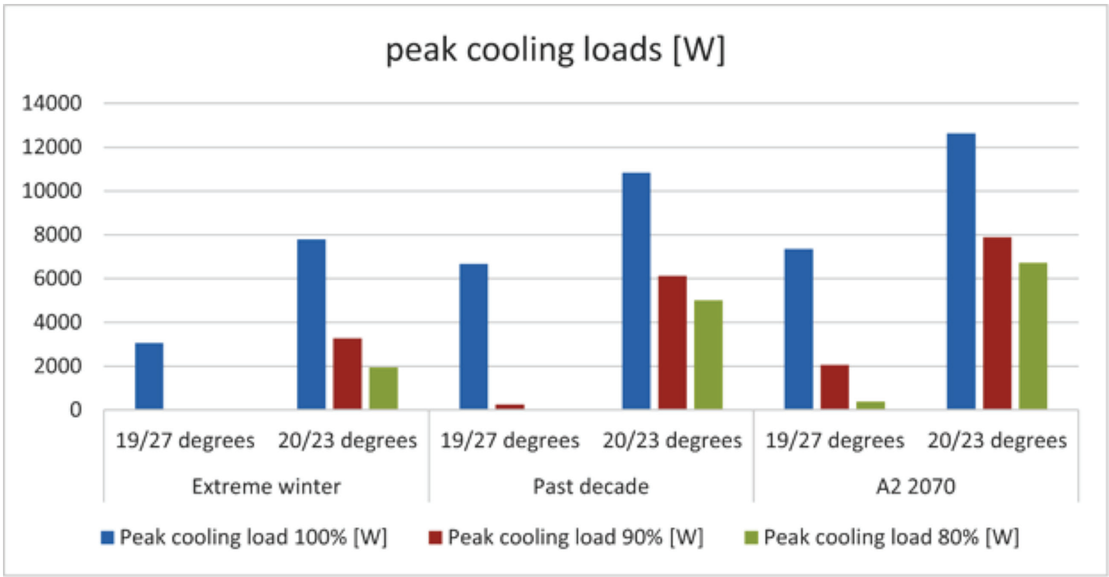
The choice of the set points for heating and cooling has also significant influence on the final energy consumption. Compared to control pattern 1, control pattern 2 leads to a reduction in final energy consumption by 20% in combination with the extreme winter scenario, to a reduction of about 25% in combination with the weather file matching 2009 conditions, and to a reduction of more than 30% in combination with the A2 climate change scenario for 2070.

Peak cooling loads

Figure 6 illustrates the peak cooling loads for the investigated building depending on the weather data set, and the conditioning controls.

Typically, conditioning systems are sized according to design days, which represent a peak load scenario that is likely to occur only during a few days per year (Thomas and Moller, 2007). This means that the conditioning system will only run efficiently at full capacity during these few days and will be over-dimensioned during the rest of the year. In order to put the occurrence of peak loads into context, in this study three versions of the peak load have been

FIGURE 6: Comparison of peak cooling loads for different weather data sets and conditioning control patterns.



compared: the 100th percentile, the 90th percentile and the 80th percentile, meaning the peak load during 100%, 90% and 80% of the year.

The results show a strong increase in peak loads for all configurations the warmer the weather data set. For the 100th percentile, the extreme winter scenario reduces the peak load by 30-55%, and the A2 climate change scenario for 2070 increases the peak loads by 10 to 15% depending on conditioning set points. For the 90th and 80th percentile these deviations tend to be even larger.

When comparing the peak cooling loads for the 100th, 90th and 80th percentile, the results show remarkable differences. For the 90th percentile, peak cooling loads are 40 - 100% lower, and for the 80th percentile they are 45-100% lower than for the 100th percentile. The reduction potential of the 90th and 80th percentile is larger for control pattern 2 compared to control pattern 1. Also the reduction potential is smaller, the warmer the weather data set.

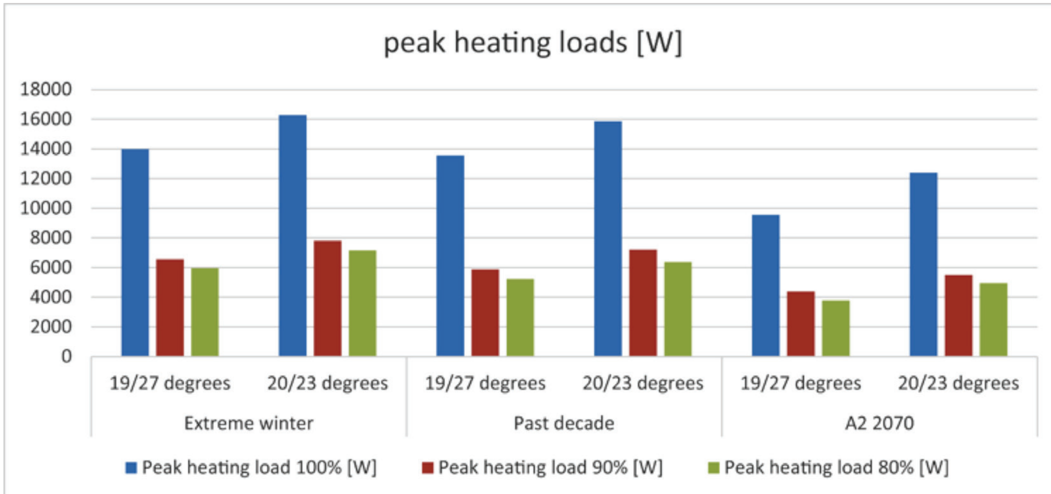
As can be expected, the conditioning control pattern has large impact on resulting peak cooling loads. Compared to conditioning control pattern 1, control pattern 2 reduces the peak cooling loads by 40 to 100%. The reduction potential is slightly smaller for the A2 climate change scenario for 2070 (40 to 95%), than for the weather file matching 2009 conditions (40-100%) and the extreme winter scenario (60-100%).

Peak heating loads

Peak heating loads are generally lower for conditioning control pattern 2 compared to control pattern 1. Also, as peak heating loads decrease, the warmer the weather data set. Compared to the weather file matching 2009 conditions, the extreme winter scenario increases the peak heating loads by about 5 to 15%, and the A2 climate change scenario for 2070 decreases the peak heating loads by about 20 to 30%. This deviation is slightly larger for conditioning control pattern 2 compared to control pattern 1.

When comparing the 100th, 90th and 80th percentile for peak heating loads, large differences can be found. The peak heating load for the 90th percentile is about 50 to 55% lower and for 80th percentile; it is 55-60% lower than for 100th percentile. Unlike for the cooling

FIGURE 7: Comparison of peak heating loads for different weather data sets and conditioning control patterns



loads, these percentages are relatively consistent for all weather data sets and both conditioning control patterns.

As can be expected, conditioning control pattern 2 significantly reduces the peak heating loads compared to control pattern 1. For the extreme winter scenario and the weather file matching 2009 conditions, this reduction is about 15 to 20%, for the A2 climate change scenario for 2070 it is about 20-30%. It is also slightly larger for lower percentiles.

CONCLUSIONS

This study investigates the impact of weather file variability as well as different conditioning set points on adaptive thermal comfort, final energy consumption as well as peak cooling and heating loads in a residential building in Victoria, Australia. The following conclusions can be summarised:

- It is important to validate weather data sets with meteorological measurements for the investigated location. Even a simplified comparison can help to evaluate whether an available weather data set is comparable to a hot, typical or cold year. This information can be crucial for a multi-year approach in building simulation.
- The percentage of occupied time where the indoor temperatures are within the limits of the ASHRAE Standard 55 adaptive thermal comfort model for 80% acceptability, varied from a minimum of 50% for the extreme winter scenario to maximum of 60% for the A2 climate change scenario for 2070. Additionally the maximum indoor temperature for the 2070 weather file was about 1 degree C higher and for the extreme winter scenario 2-3 degrees C lower than for the weather file matching 2009 conditions.
- The final energy consumption for the investigated building varied up to 40% depending on the three investigated weather files and up to 30% depending on the selected conditioning set points. In the temperate climate in Victoria, heating had the largest share in final energy consumption, and cooling the smallest share.
- The peak cooling loads for the investigated building varied by around 50% depending on the selected weather file. Additionally, the conditioning control pattern 2 reduced peak cooling by 40% and more, compared to control pattern 1.

- The impact of the three different weather files on the peak heating loads in the building can vary by up to 40% between the extremes. The use of conditioning control pattern 2 compared to control pattern 1 reduced peak heating loads by up to 30%.
- The common practice of dimensioning conditioning systems for the worst case peak load, leads to over-dimensioning of systems. The air-conditioning system for the investigated building could be dimensioned up to 50% smaller, if it was dimensioned for the 90th percentile of the time of the year instead of the maximum peak load. This provides a large potential for energy savings, especially for a house that is used only as a second home.
- The results above are valid for the investigated specific building and location. For different locations and buildings, further validation would be recommended. However the applicability of the results may be extended for the whole bioregion of the Otway Coastal plains and residential buildings with large amounts of thermal mass, potential for cross ventilation and similar assumptions for occupant behaviour. The results are not applicable for lightweight constructions, and dissimilar climates.
- It can be concluded that a multi-year approach for weather files in building simulation will demonstrate a significant variability of results depending on the climate scenario. To establish the magnitude of this variability however will require further investigation and modelling of the specific context.

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