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Sensitivity of building cooling loads to future weather predictions

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Abstract:

The interaction and relationship between the global warming and the thermal performance buildings are dynamic in nature. In order to model and understand this behavior, different approaches, including keeping weather variable unchanged, morphing approach and diurnal modelling method, have been used to project and generate future weather data. Among these approaches, various assumptions on the change of solar radiation, air humidity and/or wind characteristics may be adopted. In this paper, an example to illustrate the generation of future weather data for the different global warming scenarios in Australia is presented. The sensitivity of building cooling loads to the possible changes of assumed values used in the future weather data generation is investigated. It is shown that with ± 10% change of the proposed future values for solar radiation, air humidity or wind characteristics, the corresponding change in the cooling load of the modeled sample office building at different Australian capital cities would not exceed 6%, 4% and 1.5% respectively. It is also found that with ±10% changes on the proposed weather variables for both the 2070-high future scenario and the current weather scenario, the corresponding change in the cooling loads at different locations may be weaker (up to 2% difference in Hobart for ±10% change in global solar radiation), similar (less than 0.6%

difference in Hobart for ±10% change in wind speed), or stronger (up to 1.6% difference in Hobart for ±10% change in relative humidity) in the 2070-high future scenario than in the current weather scenario.

Keywords: Global warming, building cooling load, building simulation, future weather data, sensitivity study

1. INTRODUCTION

The cycling interaction between global warming and the buildings is of dynamic nature (Guan, 2009). Global warming would generally lead to more uses of air conditioning, which leads to more greenhouse gas emissions and then contributes further to global warming process. In order to understand this cycling interaction, various approaches have been adopted to obtain both the knowledge of how significant the built environment has contributed to the process of global warming, and how significant the global warming would impact on building performance.

In order to predict the change of building energy use due to global warming, different approaches may be used, ranging from the method of empirical statistic data (e.g. degree-day method) (Amato et al, 2005, Cartalis et al, 2001, Mirasgedis et al, 2007, Rosenthal et al., 1995; Ruth and Lin, 2006, Sailor, 2001, Sailor and Pavlova, 2003, Zmeureanu and Renaud, 2008) to the more fundamental method of building energy simulation models (Aguiar et al., 2002; Crawley, 2003; Crawley, 2007; Cullen and Lea, 2001; Degelman, 2002; Frank, 2005; Guan, 2009b; Scott et al., 1994; and Sheppard et al., 1997). In both these approaches, a set of future forecast climatic data would be necessary.

Different methods have been used to project and generate future weather data, with various assumptions embedded. From simple to complex, they may be classified as: extrapolating statistical method, imposed offset method, stochastic weather model and global climate models (Guan, 2009a). Among these four methods the first two methods (the extrapolating statistical method and the imposed offset method) are essentially modified from historically observed weather data, while the last two methods (the stochastic weather model and the global climate model) are based on fundamental physical models, using the historically observed weather data only for the purpose of model calibration.

In this paper, sensitivity of building cooling loads to the assumptions adopted in the weather model for the generation of future climatic data is investigated. After this introduction, the methodology used in the study is presented. An application of using the effective framework (Guan, 2009a) to project future weather data is then demonstrated for eight capital cities in Australia. Further sensitivity test of the possible impact of assumptions adopted in the future weather data generation on building cooling load are discussed. These include the possible changes in air humidity, solar radiation and wind characters.

2. METHODOLOGY

In order to investigate the sensitivity of building cooling loads to the assumptions adopted in future weather data generation model, the building simulation technique is employed. The method of building simulation often involves the selection of building simulation engine, selection of sample building model, and the choice of weather data for the study. In addition, the study locations covered in this study are also highlighted.

Building simulation tool

The DOE-2.1E building simulation software will be used in this study to model building energy performance. DOE-2.1E is a fully dynamic building simulation package developed by Lawrence Berkeley National Laboratory in the USA (Winkelmann et al, 1993). It has been through extensive verification process and has also been used by many countries for developing their national building energy codes (LBNL, 2010). Particularly, DOE-2.1E is able to simulate the interactions between the thermal loads in the building and the thermal mass of the building structure, and to estimate the dry bulb temperature and heating/cooling load for individual zones of modelled building. In this paper, it has been assumed that DOE-2.1E program itself is correctly coded and can accurately model the interaction between building and external climate.

Sample building model

The sample building chosen for this study is an air-conditioned, square shape, ten storey office tower with a basement carpark, which was recommended by Australian Building Codes Board (ABCB) to represent the typical office building found in the central business district (CBD) of the capital cities or major regional centres in Australia (ABCB, 2001). As described in Guan (2009b), this is a concrete office building with a footprint dimension of 35 x 35 m² and insulation value of R2.0 batts for roof and R1.5 batts for external wall. It is also assumed that window to wall ratio is 0.5 and internal load densities are 10 m² per person for occupants, 15 W/ m² for lighting and 15 W/ m² for the plug load. The building physical properties used in the hypothetical building model are in line with the design parameters used by the ABCB for the study of energy modeling of office building for climate zoning, and for the reviewing of the energy saving features of buildings in Australia (ABCB, 2002).

Current and future weather data

The approach of using single reference year weather data (i.e. Test Reference Year or TRY weather data), which is selected to represent the average weather patterns of multi-year dataset for a specific location, is adopted in this study. Based on the predicted climate change scenarios, the current TRY weather data are modified by following the effective framework (Figure 1, Guan, 2009a) to generate the future weather data for each capital city for Australia. An example to illustrate the procedure of this method will be presented in Section 3.

Insert Figure 1 here

Study locations

All eight capital cities across Australia, including Adelaide, Brisbane, Canberra, Darwin, Hobart, Melbourne, Perth and Sydney, will be considered in this study. These capital cities not only possess the majority of Australian office buildings, but also reflect the wide climate conditions of hot humid summer, warm winter (e.g. Darwin), warm humid summer, mild winter (e.g. Brisbane), hot dry summer with cool winter (e.g. Perth), warm summer with cool winter or temperate climate (e.g. Sydney, Melbourne and Adelaide) and mild to warm summer with cold winter or cool temperate climate (e.g. Hobart and Canberra).

3. METHOD OF GENERATING THE FUTURE WEATHER DATA

In this section, an example to illustrate the detailed procedures to generate future hourly weather data for the different global warming scenarios in Australia is presented. This is achieved by following the effective framework shown in Figure 1. It can be seen that in this method, two sets of input data are required, i.e. the current reference year weather data and the projected change of weather variables due to global warming. The advantages of this method is that depending on the provision of information in the prediction of future changes in weather variables, either the method of retaining current weather variable unchanged, or imposed offset method or diurnal modeling method may be employed to generate the future hourly weather data. That is, the current reference year weather data contained in TRY (Test Reference Year) / TMY (Typical Meteorological Year) is either used directly, or used as the base for further modification, or used for the calibration of diurnal modelling of meteorological parameters. This therefore represents a more comprehensive and holistic approach to convert the available weather data and climatic information to a format suitable for building simulation study.

Input data

Only two sets of input data are required in the current method, including the current reference year weather data and the projected change of weather variables due to global warming (e.g. the projected temperature increase). In most cases, both of them may be readily available or easily accessed. For instance, the typical reference year weather data is often currently available for building simulation practice. The projected change of weather variables under climate change is also normally available from either the Data Distribution Centre (DDC) of the Intergovernmental Panel on Climate Change (IPCC, http://www.ipcc-data.org) or relevant national research organizations in each country. However, it is noted that the completeness and resolutions of predicted weather variables may be varied with different climate models selected for different countries.

- *Current reference year weather data*

A typical reference year is defined as a whole calendar year, which is intended to represent the long term weather patterns at a given location. The effectiveness of a typical reference year, however, relies on how it is selected and what sort of data it is based on. Generally, a typical reference year may be classified into two categories. The first type is to use the year selected to represent the average weather patterns that would typically be found in a multi-year dataset for a particular location. It is a whole natural calendar year data derived from observation at a specific location by the national weather service or meteorological office.

In parallel, the second type of weather data instead consists of linked monthly segments of weather data selected from the (different-year) historical meteorological records. The selected meteorological data are identified by the closeness of the cumulative distribution functions. For this purpose, Finkelstein-Schafer statistic method, for example, may be used (Levermore, 2006). The general view is that selection based on linked months (the second type) has a better chance of forming a "year" close to the long term average (Adelard, et al, 2000). It has also been found that the careful uses of the representative climate data are particularly important in computer simulations of building designs and their resultant energy needs (Degelman, 2007).

In this study, the current TRY weather data for all the state capital cities around Australia are supplied by ACADS-BSG, a specialist consulting company based in Melbourne, Australia. The weather variables contained in this Australian climatic database include dry bulb temperature (DBT), humidity ratio (w), atmospheric pressure (P), wind speed and direction, cloud cover, global solar irradiance on a horizontal plane, diffuse solar irradiance on a horizontal plane and direct solar irradiance on a plane normal to the beam.

- *Projected change of weather variables due to global warming*

Methods of predicting climate change have been the subject of intense research in recent years, and they are now able to yield reasonable estimates of generalised future values (such as annual means) together with the indication of likely future variability (Levermore & Keeble, 1998). These predictions are typically based on models of global climate “forced’ by a presumed finite or continuing change in atmospheric carbon dioxide concentration. Estimations of trends over large areas are also generally considered more accurate than those over small areas.

Unlike most other scientific work, such predictions cannot be validated, since they do not relate to a currently replicable event. However, for different climate parameters, there are different levels of confidence (Table 1). Among them, the projection of change in dry bulb temperature is claimed to have the greatest confidence among the other key weather variables considered for the building simulation. Indeed, unlike projection of future dry bulb temperature change, which can often be seen in many climate change brochures, it is also noted that the projection of possible change in air humidity, solar radiation or wind characteristics is limited and much less consistent (Sailor, 2001).

Insert Table 1 here

For Australia, the information on the likely future global warming is provided by the Government research agency CSIRO (Commonwealth Scientific & Industrial Research Organization). The projected seasonal dry bulb temperature change for the years of 2030 and 2070 is shown in the Figure 2 (CSIRO, 2001), which is also interpreted and tabulated in Table 2. The years of 2030 and 2070 are used to represent respectively the short and long term of future climate change scenarios. The so-called ‘Low’ and ‘High’ scenarios for each projected year have been used to span the most likely range of possibilities. This is due to the limitation of current climate models and the uncertainties of future GHG emissions, which are subject to the future population growth, technological change, and social and political behaviour, etc.

Insert Figure 2 here

Insert Table 2 here

Compared with the more recently released CSIRO projections (CSIRO, 2007), it has been found that the spatial patterns of temperature change remain similar, but a narrower range of warming is predicted by the new updated 2007 model than that determined in 2001. For example, a new range of 1 to 5 ºC is now projected in comparison with previous projection of 1 ºC to 6 ºC for 2070. This is partly attributed to the improved consistency between different models.

Preparation of future hourly weather data

In this study, only the projected change in dry bulb temperature (DBT) is assumed to be available, while the possible changes of other weather variables, including air humidity, solar radiation and wind characters, are ignored in the first place.

The reasons for this assumption are as follows:

- The information on the projection of future dry bulb temperature change has relatively high confidence and can often be seen in climate change brochures;
- When the method of empirical statistic data (e.g. degree-day method) is employed, only the potential increase in temperature is effectively considered;
- When the building simulation method is used to predict building performance under future climate change, the potential increase in temperature is always the key parameter to be

considered, while various assumptions may be made for other climatic parameters (Guan, 2009a).

The imposed offset method as shown in the effective framework (Figure 1) is also chosen for this study to generate future hourly DBT data. This means that only the projected temperature change is imposed on to the current test reference year (TRY) weather data, while the relative humidity, solar radiation and wind speed are assumed to remain at the current level. An example of the application of this method to the different global warming scenarios in Australia is also presented below. Only the dry bulb temperature (DBT) and relative humidity (RH) are illustrated here.

- *Dry bulb temperature*

Based on the projected seasonal temperature change shown in Figure 2 and Table 2, the imposed offset method, or morphing approach (Belcher et al, 2005) can be used to modify the current test reference year (TRY) weather data for each site, through a constant temperature increase for every hour within each season as expressed in equation 1:

$$T_n(i) = T_o(i) + \Delta T(i) \tag{1}$$

where

T_n – hourly dry bulb temperature for future climate (°C)

T_o – hourly dry bulb temperature at current climate (°C)

ΔT – hourly predicted temperature increase (°C)

By this way, the projected seasonal temperature changes are incorporated to the current reference year weather data to reflect the effect of potential future global warming. For a specific study location, as shown in Table 2, ΔT is varied with different seasons and with different future climate scenarios. T_o is the hourly dry bulb temperature from the current test reference year which is only varied with different locations. For each site there will be four future climate scenarios, called 2030 Low, 2030 High, 2070 Low and 2070 High scenarios. If it is preferred, the seasonal prediction could also be converted to monthly prediction using the interpolating calculation method (BRANZ, 2007).

The distributions of percentage of hourly outdoor temperature (DBT) for the different climate scenarios are shown in Figure 3. It can be seen that using this method, all four future climate scenarios would have similar distribution pattern with that of current TRY weather data. This is consistent with the comparison between cold and hot years weather data (Guan, 2007). This result also indicates that the similar diurnal temperature cycle has been retained in this model. It is also noted that the extreme part of temperature (the first and last 10% to 20%) is subject to most of the changes for the different future climate scenarios, while for the middle part (20% to 80%) the distribution lines are closely in parallel, which indicates that a similar distribution profile exists between the different climate scenarios. It also seems that for the middle part, there is nearly a linear relationship between outdoor dry bulb temperature and the cumulative percentage of hours per year.

Insert Figure 3 here

- *Air humidity*

Since the possible change in air humidity is ignored in this paper, as a first approximation, the relative humidity, instead of absolute humidity, may be assumed to remain unchanged to allow for the possible increase of evaporation due to global warming (Sturman & Tapper, 2005).

In the test reference year (TRY) weather file, the information regarding to the air humidity is typically represented by the humidity ratio (W_o). In order to calculate the future new humidity ratio (W_n), the standard meteorological formulas, which can be found in ASHRAE handbook (ASHRAE, 2009) and are often used to create psychrometric charts, are used here for the conversion between relative humidity (RH) and humidity ratio (W). This procedure may be summarized as follows:

First, calculate the existing relative humidity (RH_o) at the given dry bulb temperature (T_o), humidity ratio (W_o) and atmospheric pressure (P_o)

$$RH_o(i) = f\,(T_o, W_o, P_o)_i \qquad (2)$$

Because the new relative humidity (RH_n) and atmospheric pressure (P_n) are assumed to remain unchanged

$$RH_n(i) = RH_o(i) \qquad (3)$$

$$P_n(i) = P_o(i) \qquad (4)$$

So the new humidity ratio (W_n) can be recalculated as

$$W_n(i) = g\,(T_n, RH_n, P_n)_i \qquad (5)$$

where

T_n – hourly dry bulb temperature for future climate (°C)

RH_n – hourly relative humidity for future climate, dimensionless

W_n – hourly humidity ratio (or absolute humidity) for future climate ($kg/kg_{\text{dry air}}$)

P_n – hourly atmospheric pressure for future climate (Pa)

T_o – hourly dry bulb temperature at current climate (°C)

RH_o – hourly relative humidity at current climate, dimensionless

W_o – hourly humidity ratio (or absolute humidity) at current climate ($kg/kg_{\text{dry air}}$)

P_o – hourly atmospheric pressure at current climate (Pa)

It may be noted from above that atmospheric pressure has also been assumed to remain unchanged in this study. This assumption is based on the analysis of ten year historic climatic data, which has found that there is no clear correlation between hourly variations of atmospheric pressure and air temperature (Guan et al, 2007). By comparing atmospheric pressure between the hottest and the coldest years in the ten year period, it has also been found that there is no significant change between them (Guan, 2007). This may be because although the air temperature and moisture level can alter the atmospheric pressure at any given altitude, the altitude still actually exerts the dominant influence.

The distribution of percentage of hourly outdoor air humidity ratio for the different climate scenarios is shown in Figure 4. It can be seen that the differences of air humidity ratio between different climate scenarios has become more significant with the increase of cumulative percentage of hours. This indicates that the higher the outdoor air temperature, the more seriously the air humidity will be affected by the possible increase of the air temperature. This appears to be reasonable, given that the higher the air temperature, the faster the water would evaporate and the higher the ability of air to hold water vapor.

Insert Figure 4 here

Using the above future weather data, the energy performance and indoor thermal environment of the sample office building have been projected under various future climate scenarios and have been reported by Guan (2009b). It was found that if the annual average temperature increase is over 2°C, then the risk of current office buildings subject to overheating will be significantly increased. In addition, it was also found that for existing buildings designed using current climate condition, the increase of building cooling load for Australia is typically 2-3% for 2030 Low scenario, 9-14% for 2030 High scenario, 5-8% for 2070 Low scenario and 27-47% for 2070 High scenario.

4. SENSITIVITY OF BUILDING COOLING LOAD TO THE ASSUMPTIONS

Since the sky cloudiness, the rate of water evaporation and wind character could change with global warming, the impact of the assumption to retain current level of solar radiation, relative humidity and wind speed would therefore need to be investigated. It is noted that only two extreme climate scenarios, the current climate and the 2070 High scenario, are used in this sensitivity study. It is believed that the behaviour of the other three climate scenarios, called 2030 Low, 2030 High and 2070 Low, can be estimated from the results of these two extremes. Also for this sensitivity study, only the building cooling load is studied. This is because:

- With global warming, the heating load will be reduced and the cooling load will be increased. Therefore, cooling energy is the main contributor to the possible increase of total energy use in office buildings.
- Office buildings are typically internal-load dominated. The heat load generated by internal load often provides more heat than that an occupied office space would require during most time of the year, particularly for temperate climate in Australia. Therefore, the energy used to offset the cooling load is often much more significant than that for the heating load.

In total, there are 128 simulation runs performed for this sensitivity study, with 32 for solar radiation (8 locations x 2 weather scenarios x 2 cloud cover levels), 64 for relative humidity (8 locations x 2 weather scenarios x 4 humidity levels), 32 for wind speed (8 locations x 2 weather scenarios x 2 wind speeds).

Solar radiation

Accurate projection of the changes in solar radiation due to increased cloud cover from greenhouse gases is difficult. Changes in cloud cover associated with global climate change, and how such cloud-cover changes interact with a change in climate (i.e., cloud feedback), remain one of the most challenging aspects of future climate change research (Croke et al, 1999). In order to test the sensitivity of building cooling load affected by the solar radiation, in this paper, the level of cloud cover is uniformly increased/decreased by one level from the current reference year. Through DOE-2 weather processor, the consequent change in global solar radiation (GSR) is then calculated. It is found that the resulted change in GSR is varied from the smallest change of 8.5% in Perth to the largest change of 19.3% in Hobart.

The effect of change in GSR on the building cooling load for both current and 2070-High weather scenarios are shown in Figure 5 (a) and (b) respectively. By comparing the slopes of lines for different locations in the same weather scenario and the same location in the different weather scenarios in Figure 5, it can be found that the effect of change in GSR on the building cooling load would be weaker at a hotter place and greater at a cooler place. This is reasonable because if every condition is the same except for air temperature, then for a hotter place the portion of solar radiation contributing to the building cooling load would be smaller, which would mean that its influence on the percentage of change in total building cooling load would be relatively weaker.

Insert Figure 5 here

If the (absolute) change of building cooling load is plotted against the percentage of change in GSR (Figure 6), it can be found that there is an extremely good linear correlation between them, with R^2 value (the coefficient of determination) being 0.9952 and 0.9948 for current and 2070-high weather scenarios respectively. This indicates that the effect of percentage of change in GSR on the absolute change in building cooling load is somehow independent of both localities and weather scenarios. This is consistent with the phenomenon shown in Figure 5 which indicates that the hotter the place, the less percentage change of the building cooling load. The comparison of trendlines between the current and 2070-high weather scenarios in Figure 6 shows that they are almost overlapped with each other.

Insert Figure 6 here

Relative humidity

Based on an analysis of ten years historic weather data for all the capital cities in Australia, it has been found that there is approximately a linear relationship between dry bulb temperature (DBT) and air relative humidity (RH) (Guan et al, 2007). With four degree temperature variation, the change in air relative humidity may be around 20%. Therefore, the effect of ±10 to 20% of variation in RH from the base value is examined in this paper to take account of possible dryer/wetter climate around different cities in Australia. It is noted that the hourly change of RH may be limited in the high RH range, as the RH would never go above 100%. When the air reaches saturation, the water vapour would start to be condensed out. Therefore, when increasing

RH by 10 to 20%, the increase of absolute humidity may be less than 10 to 20%, if the RH for current weather scenario has already reached higher than 80%.

The effect of change in relative humidity on the building cooling load is shown in Figure 7. It can be seen that there is a nearly linear relationship between the change of RH and its effect on the building cooling load. With a decrease of RH, the building cooling load would also decrease. It also appears that the effect of change in RH on the building cooling load varies from one place to another. The hotter the place, the stronger effect of change in RH on the building cooling loads.

Insert Figure 7 here

Compared with the current weather scenario, the difference between different cities becomes smaller for the 2070 high weather scenario. It is also interesting to note that although the largest effect of RH on building cooling load has almost remained unchanged in Darwin for both weather scenarios, the effects in other cities are actually more significant for the 2070-high weather scenario than the current weather scenario, getting closer to the effect in Darwin. This may indicate that the impact of variation in RH on the building cooling load would become more significant with global warming scenarios.

Wind speed

It is generally accepted that the influence of wind speed on thermal design load and building energy consumption are relatively less important, except for in locations where severe wind conditions predominate. The effects of wind data on thermal designs and energy analysis of buildings are also difficult to define and quantify (Lam, et al, 2005). Therefore, in this paper, an arbitrary ± 10% of change in wind speed is chosen for the sensitivity study of wind speed on the building cooling load.

The effect of change in wind speed on the building cooling load is shown in Figure 8. It can be seen that there appears to be a good linear relationship between the change in wind speed and the change in building cooling load. The greater the wind speed, the less building cooling load would be required. This appears to be reasonable, given that the higher the wind speed, the more heat would be lost from the building envelope.

Insert Figure 8 here

It is also noted that the effect of wind speed on the building cooling load is quite weak. With 10% of variation in wind speed, the change in building cooling load would be less than 1.5% for the current weather scenario. Compared with the current weather scenario, it is also noted that the effect of change in wind speed on the building cooling load would be even smaller for the 2070 high weather scenario. This may indicate that with the global warming weather scenarios, the variation in wind speed would have less impact on the building cooling load than the current weather scenario.

In contrast with mechanically cooled building as studied in this paper, for natural ventilation buildings, the data of both wind direction and speed can be very important and would have a significant implication on building design, especially in the calculation of ventilation air exchange and the possible infiltration (Guan, 2008).

Overall findings from the sensitivity study

In summary, it has been found from the above sensitivity study that the relationship between building cooling load and the changes of the weather variables of solar radiation, relative humidity or wind appears to be reasonably linear. By comparing the effect of change in global solar radiation (sky cloudiness), air relative humidity and wind speed, it has been found that the change in global solar radiation has the greatest effect on the building cooling load, while the wind speed the least. With ± 10% change of each weather variable, the change in sample building cooling load would be less than 6% for solar radiation, 4% for relative humidity and 1.5% for wind speed.

It is shown that compared with the current weather scenario, in the 2070-high future scenario, the impacts of such changes on sample building cooling load would vary from weak, similar, to strong for different weather variables at different locations. At a hotter place, the relative effect of change in solar radiation on the building cooling load would be weaker in comparison with that at a cooler place. This is in contrast with the effect of relative humidity. The effect of wind speed on the building cooling load is rather weak.

However, it is also noted that this result may be subject to the influence of the building size and type. It would be normally expected that smaller buildings, with their higher surface-to-volume ratio, would be more significantly affected by insolation and wind change. Therefore, it is stressed here that because the impact of specific weather variable on building performance would vary for different types of building design at different locations, individual sensitivity test of the implication of each assumption on the study building is needed to show the extent of its possible impact on building performance. This is crucial for the success of impact study of climate change on a certain type of building design.

5. CONCLUSIONS

Greenhouse gas emissions and associated global warming is a significant concern for the world community. In order to conduct quantitative analysis of the impact of global warming on the built environment, the provision of suitable forecast weather data are often necessary. In this paper, an example to generate future weather data for the different global warming scenarios in Australian capital cities has been presented. The sensitivity of building cooling loads to the possible changes of assumed values adopted in the future weather data generation is investigated.

It has been shown that with ± 10% change of the proposed future values for solar radiation, air humidity or wind characteristics, the corresponding change in the cooling load of the modeled sample building is predicted to be less than 6% for solar radiation, 4% for relative humidity and 1.5% for wind speed. It has also been found that with these ±10% changes on the proposed weather variables, the corresponding change in the cooling loads at different locations may be weaker (up to 2% difference in Hobart for ±10% change in global solar radiation), similar (less than 0.6% difference in Hobart for ±10% change in wind speed), or stronger (up to 1.6% difference in Hobart for ±10% change in relative humidity) in the 2070-high future scenario than in the current weather scenario. These results may be subject to the influence of the building size and type.

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Table 1: List of climate and associated scenario variables, ranked subjectively in decreasing order of confidence (Hulme and Sheard, 1999).

Climate variable	**Confidence**
Atmospheric CO2 concentration	**High** ↓ **Low**
Global –mean sea–level	
Global –mean temperature	
Regional seasonal temperature	
Regional temperature extremes	
Regional seasonal precipitation and cloud cover	
Regional potential evapotranspiration	
Changes in climatic variability (e.g. E1 Nino, daily precipitation regimes)	
Climate surprises (e.g. disintegration of the West Antarctic Ice Sheet)	Very low or unknown

Table 2: The projected seasonal temperature change for years 2030 and 2070

	Summer				Autumn				Winter				Spring			
	2030		2070		2030		2070		2030		2070		2030		2070	
Location	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Adelaide	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2
Brisbane	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2
Canberra	0.4	2	1	6	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2
Darwin	0.3	1.7	0.8	5.2	0.4	2	1	6	0.4	2	1	6	0.4	2	1	6
Hobart	0.3	1.4	0.8	4.3	0.3	1.4	0.8	4.3	0.3	1.4	0.8	4.3	0.3	1.4	0.8	4.3
Melbourne	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.4	0.8	4.3	0.3	1.7	0.8	5.2
Perth	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.3	1.4	0.8	4.3	0.3	1.4	0.8	4.3
Sydney	0.4	2	1	6	0.3	1.7	0.8	5.2	0.3	1.7	0.8	5.2	0.4	2	1	6

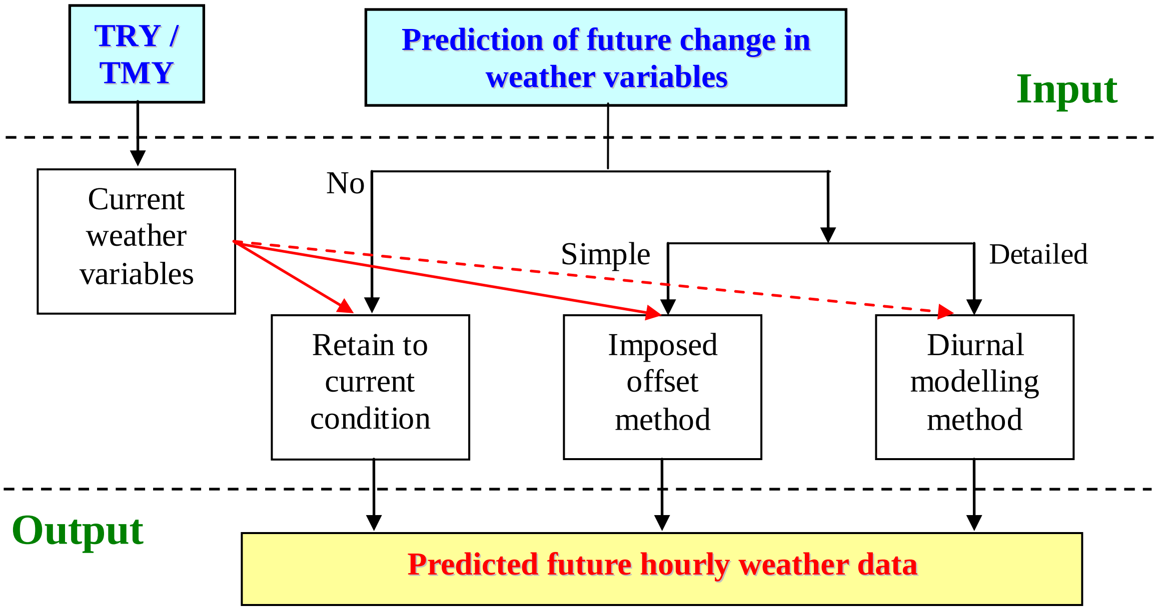


Figure 1: The effective framework to estimate the change of weather variables due to global warming (Guan, 2009a)

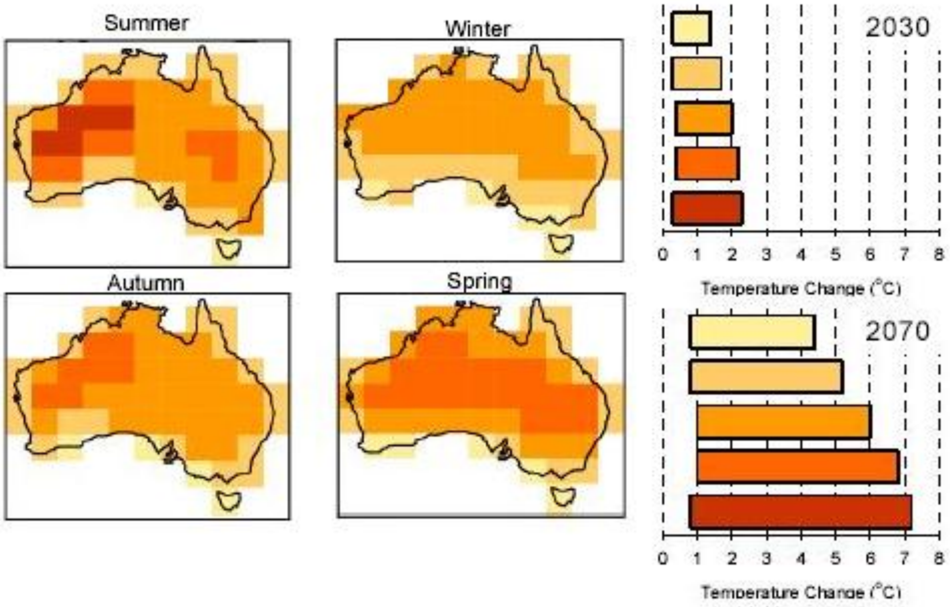


Figure 2: Ranges of possible seasonal average warming in Australia, relative to 1990 (CSIRO, 2001)

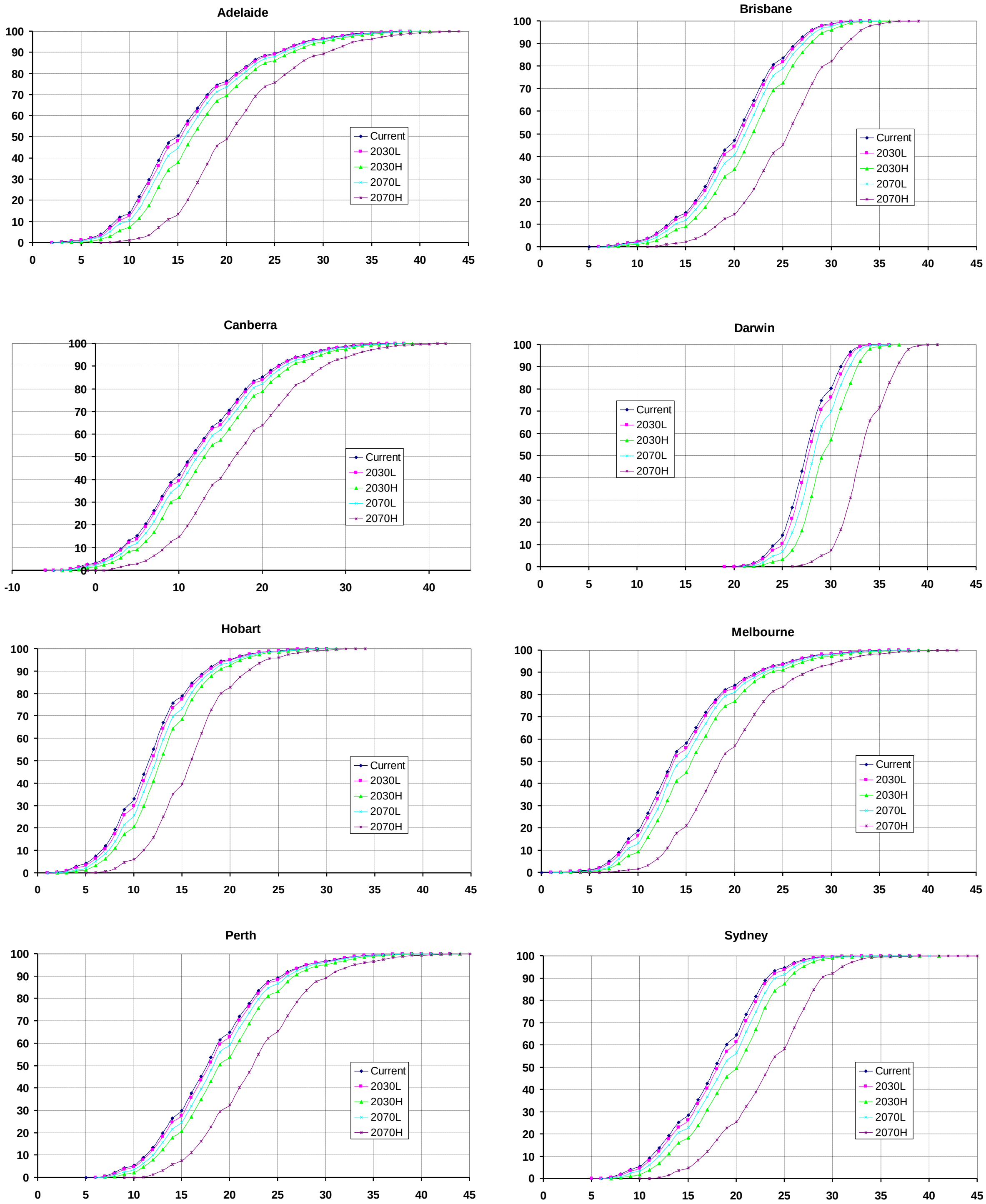


Figure 3: The cumulative frequency of hourly DBT for the different climate scenario. The X-axis represents outdoor dry bulb temperature (°C) and the Y-axis represents cumulative percentage of hours per year (%)

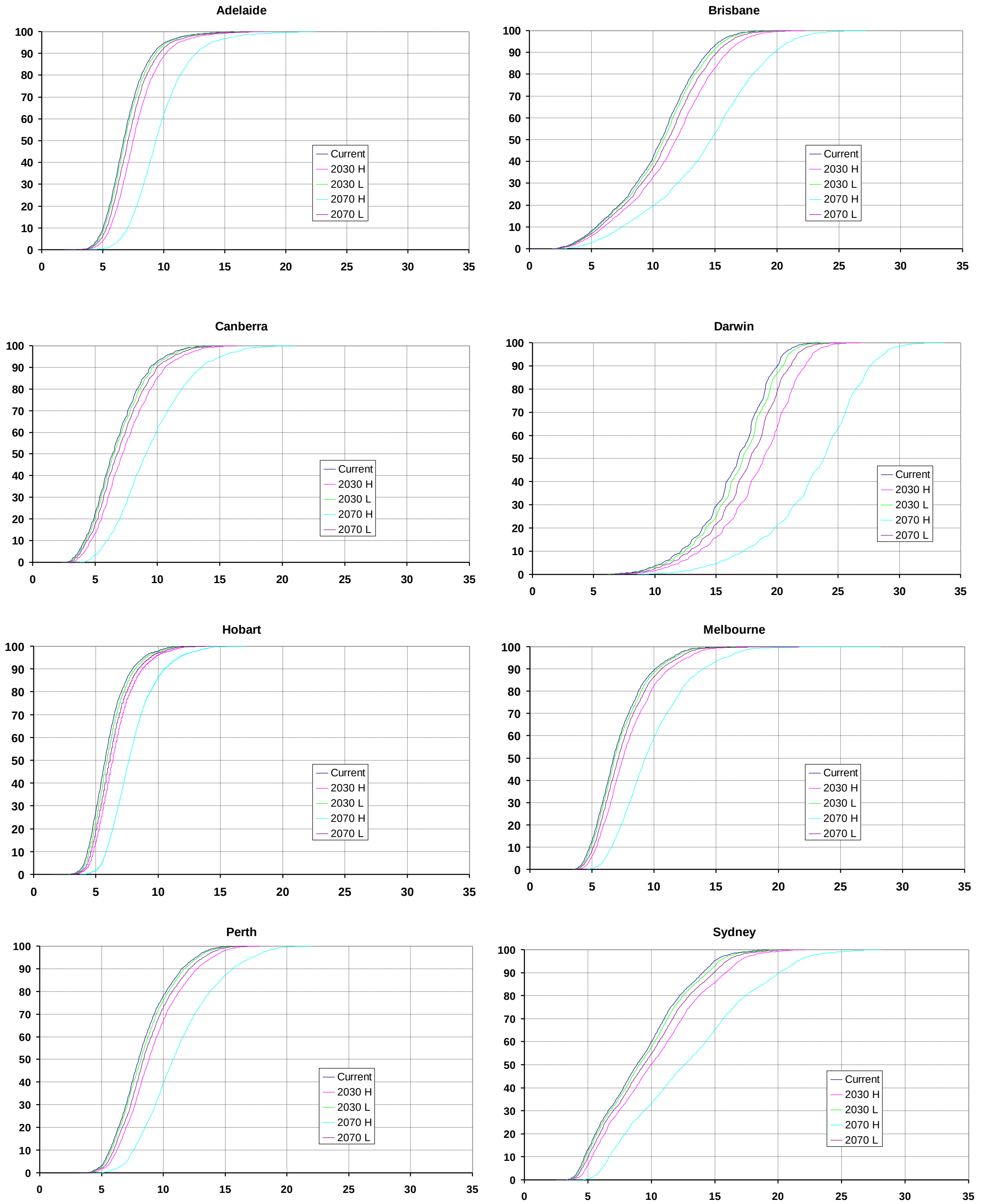
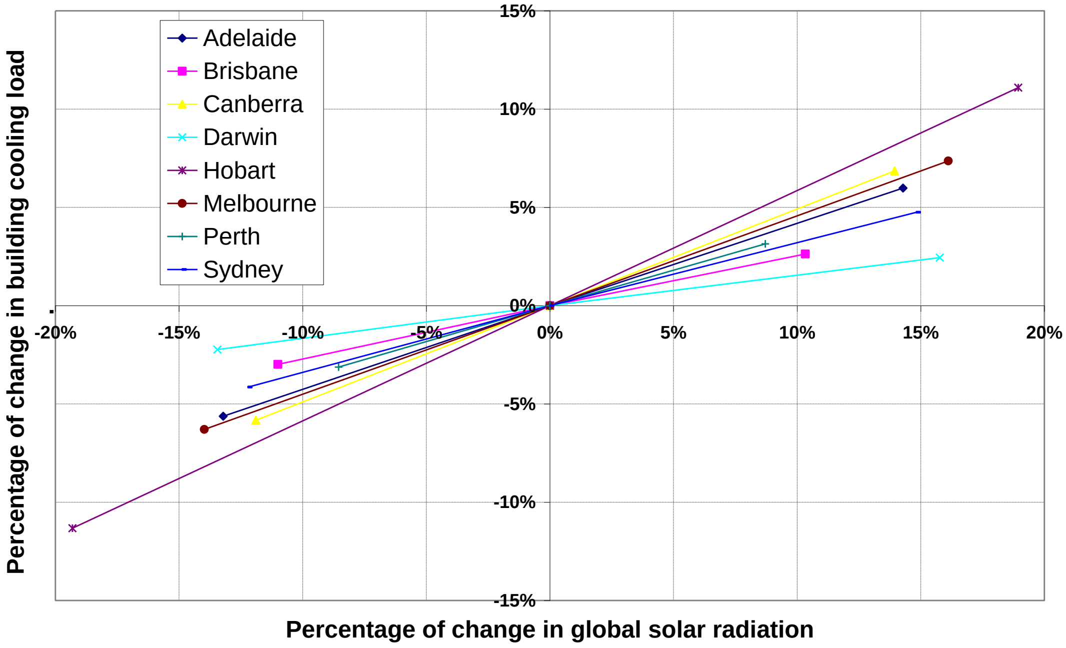
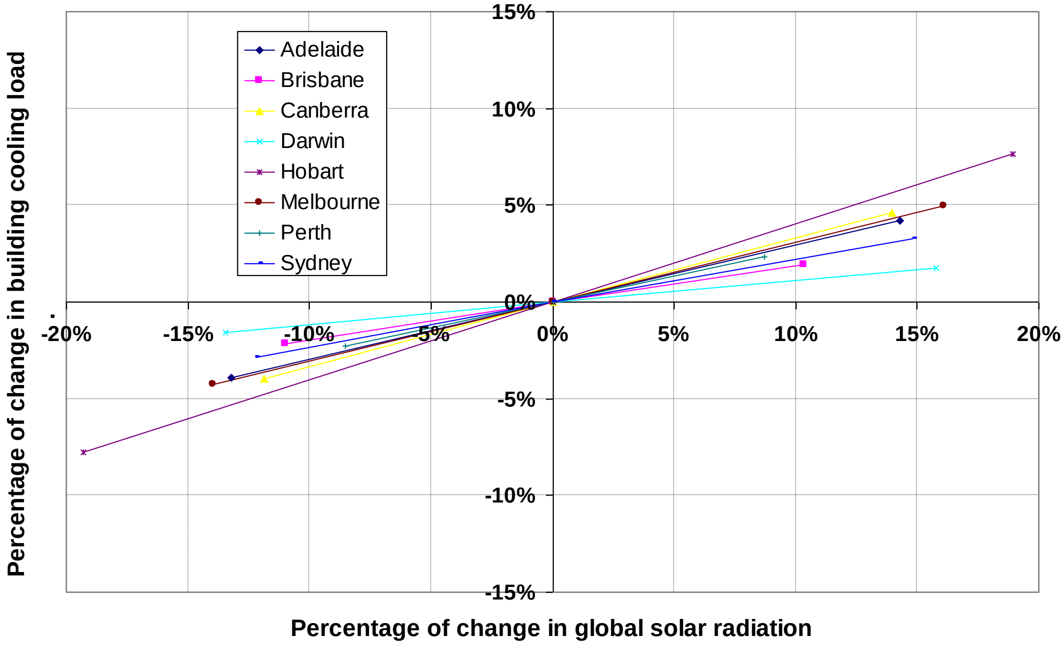


Figure 4: The distribution of percentage of hourly outdoor air humidity ratio for the different climate scenario. The X-axis represents air humidity ratio (g/kg dry air) and the Y-axis represents cumulative percentage of hours per year (%)



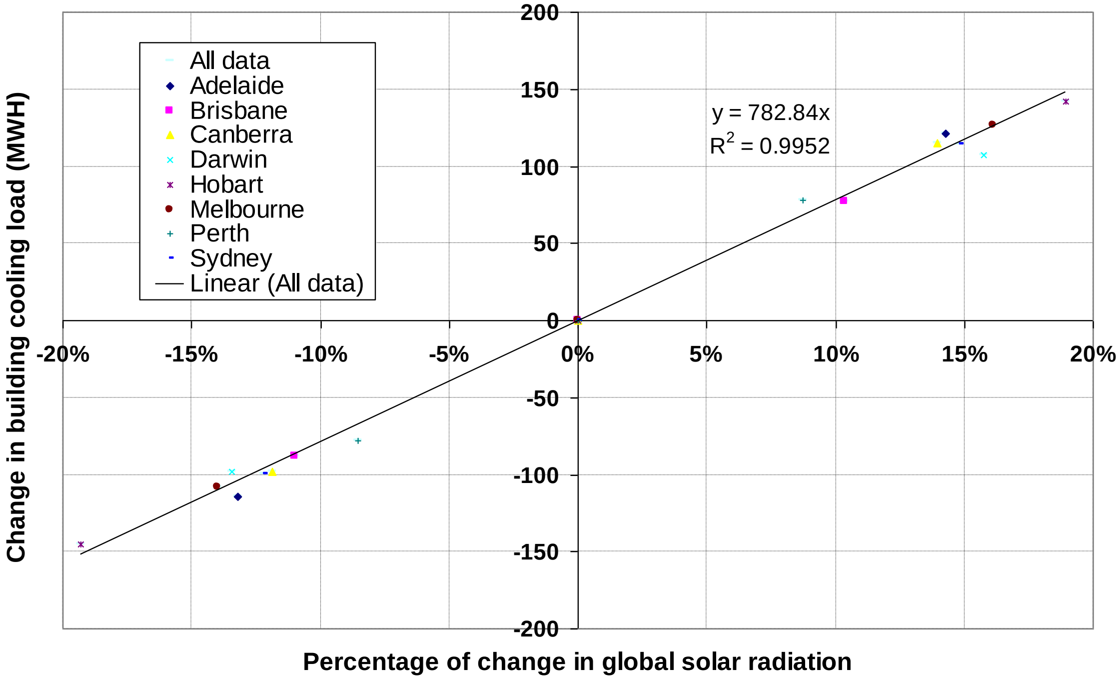
(a) Current weather scenario

(b)

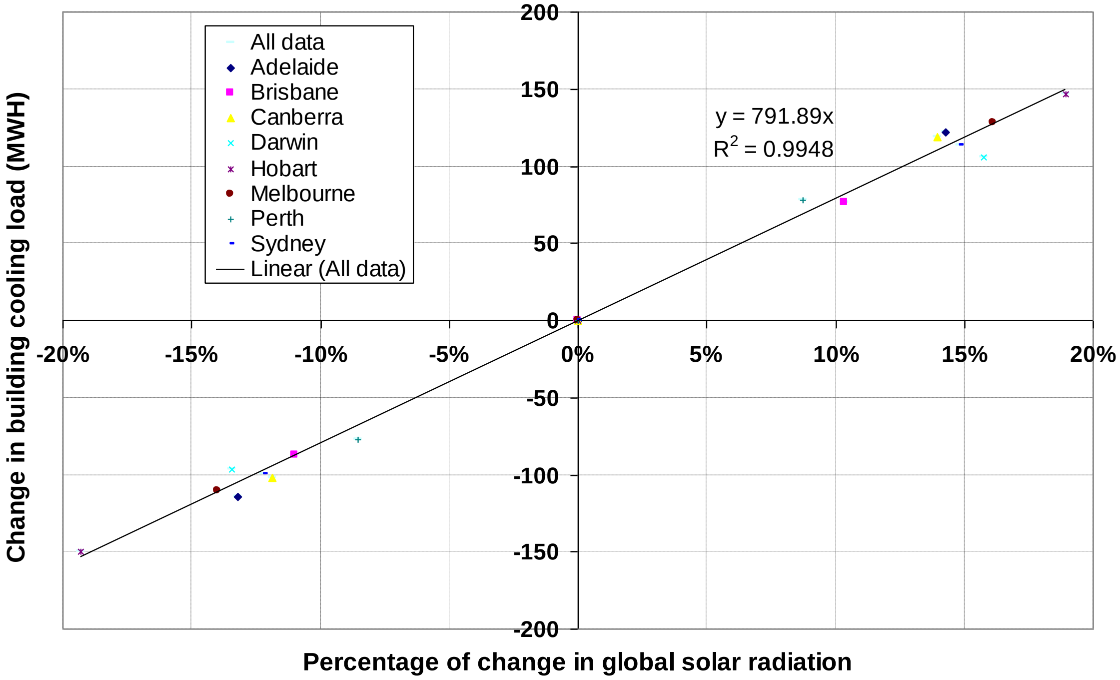


b) 2070-High weather scenario

Figure 5: The effect of change in GSR on the building cooling load

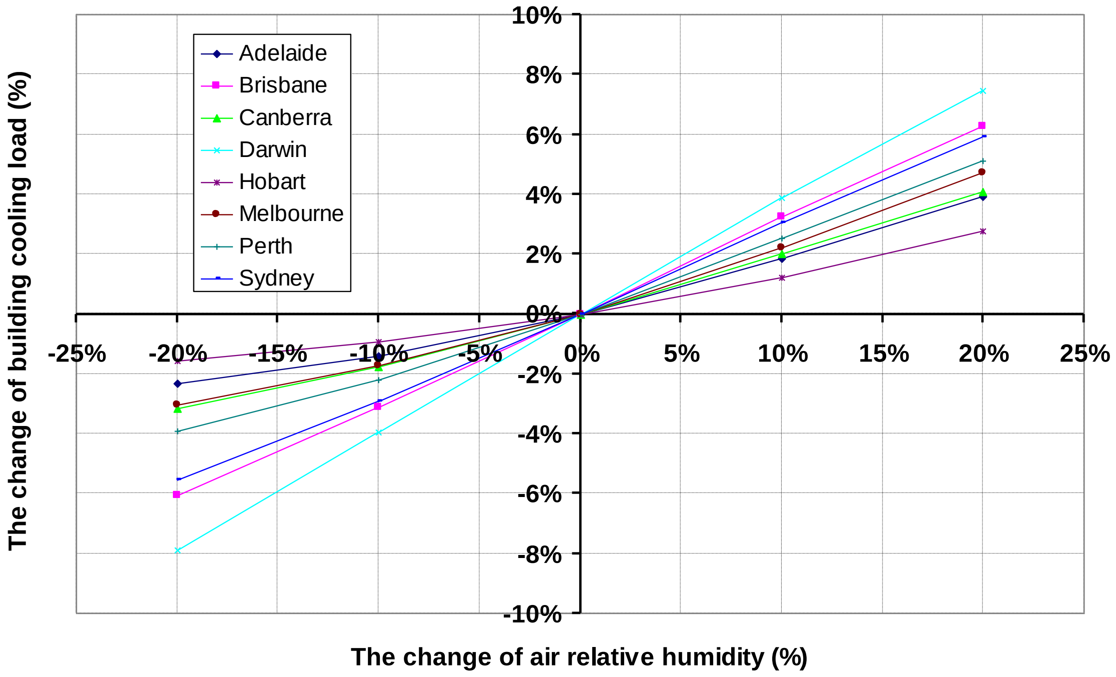


(a) Current weather scenario

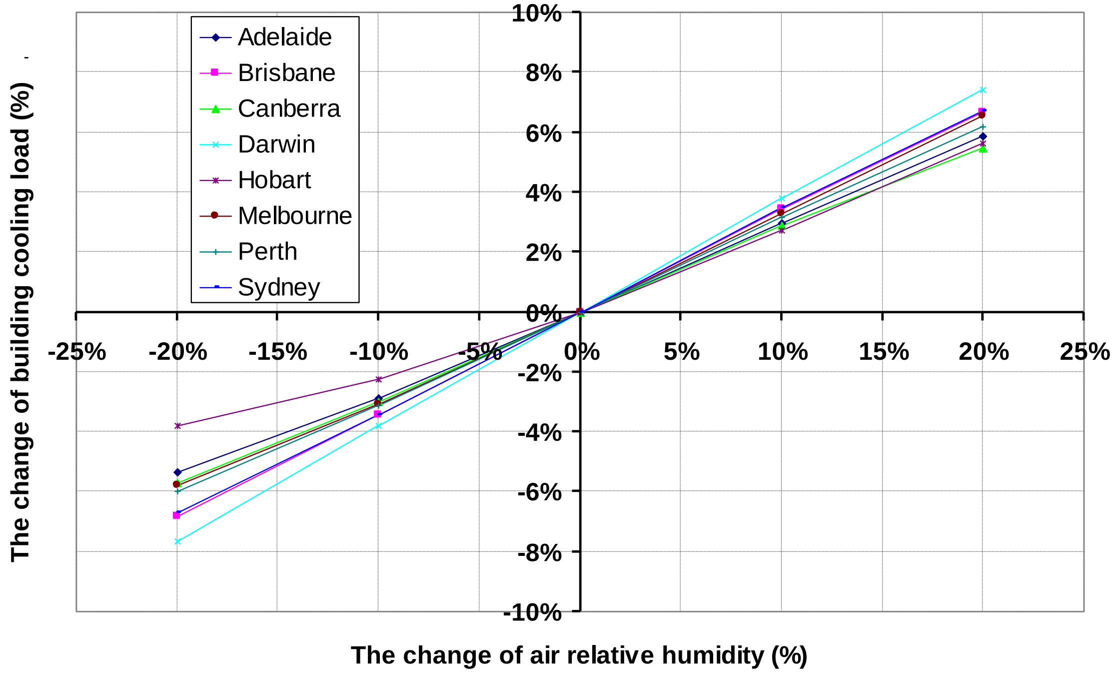


(b) 2070-High weather scenario

Figure 6: The absolute change of building cooling load due to varied in GSR

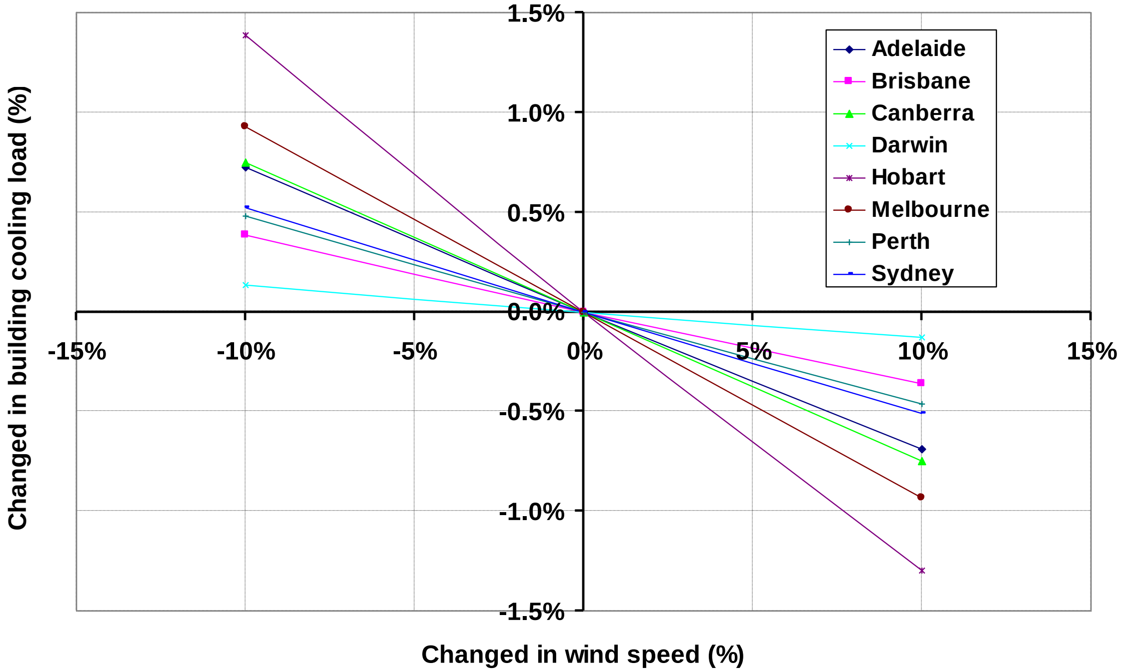


(a) Current weather scenario

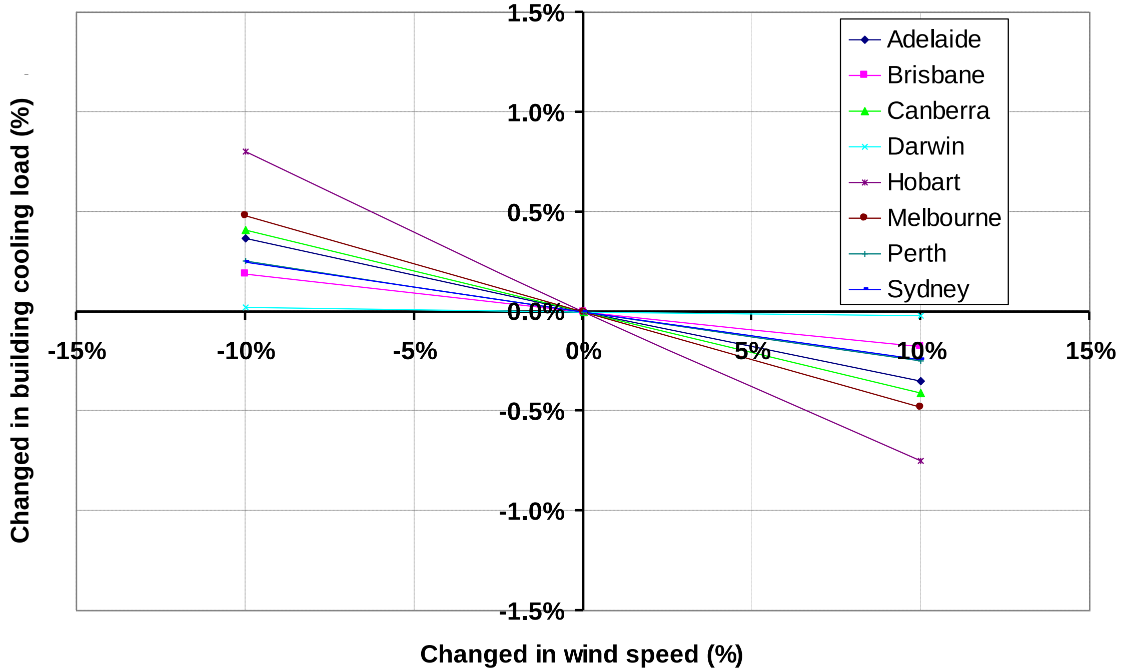


(b) 2070-High weather scenario

Figure 7: The effect of change in relative humidity on the building cooling load



(a) Current weather scenario



(b) 2070-High weather scenario

Figure 8: the effect of change in wind speed on the building cooling load