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The effect of future climate change on indoor thermal environment of a natural ventilated urban apartment in Taiwan

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1. Introduction

The outdoor climate is gradually changing under the influence of global warming effect. It is speculated that the occurrence of overheating days will increase and that of overcooling days will decrease. Unquestionably it will have certain degrees of impact to the building energy use, especially on the cooling energy. In Taiwan, building energy use also comprises 30% of the total nation-wide energy. Therefore, to achieve rational use of energy in the context of future climate, it's crucial to understand the potential global warming impact on the building's thermal performance and take appropriate adaptation measures to prevent unnecessary energy waste either from the perspective of energy saving design or operational management. The influences of global warming on building energy performance and the corresponding adaptive strategies have gained much attention worldwide. Belcher et al. [1] firstly proposed a spatial-temporal downscaling method, i.e. the morphing method, to utilize monthly meteorological change predicted by atmosphere-ocean general circulation model (GCM) in generating future hourly weather years dedicated for building simulation. This study followed the morphing method in producing future hour meteorological data for building simulation purpose base on typical meteorological years (TMY3) of Taipei for the study of climate change impact on the cooling energy influences of a hybrid-ventilated residential apartment in hot-and-humid Taiwan. The objectives of this study are: (1) To construct a future climate responsive hourly weather years for building simulation utilization. (2) To discuss annual building energy variations under global warming influences. (3) To appraisal the potential of various remodeling strategies in improving building energy performance.

2. Methodology

2.1 Morphing method

Computer simulation tools are usually adopted in building thermal and energy performance studies. These tools usually use hourly weather data for sub-hourly simulation. Since the predicted future weather data are often given in monthly terms and are spatially covered over hundreds of kilometers, temporal and spatial downscaling process is needed. Based on Belcher et al., the morphing method adopts either shifting, linear stretching, or a combination of shift and stretch to morph the observed weather variables base on the GCM predicted changes for conducting downscaling processes. The method involves three transforming function to different weather variables in preserving their consistency and weather sequences:

(1) Shifting

Shift morphing superimpose a given monthly predicted change (Δx_m) on the present day weather variables (x_0), and as:

$$x = x_0 + \Delta x_m \qquad (1)$$

Whereby, ∆xm denotes to the absolute monthly change in the given future m month of a certain weather variable. Whenever an absolute change value is given to describe the variation of certain weather variable, shift morphing is applied, such as atmospheric pressure.

(2) Linear stretching

Linear stretch morphs the present day weather variable (x_0) by multiplying with a scaling factor (α_m), and takes the form as:

$$x = \alpha_m x_0 \qquad (2)$$

Where, αm is a scaling factor calculated from the proportional change between monthly mean values in a given future m month and the observed baseline climate of a certain weather variable. When the description of the amount of monthly climate change is given by a relative value or proportional value, or when the value of the weather variable may be zero in nighttime, the linear stretch morphing is used, such as global solar irradiation and diffuse/direct solar radiation.

(3) Combination of shift and stretch

For weather variables having future variation traits of shifting and stretching, a combination of shift and stretch morphing is used, and as eq. 3. Ambient temperature is an example of this, except for the adjustment of monthly mean, monthly amplitude corrections calculated based on the predicted and the present days' monthly maximum and minimum temperatures should also be considered.

$$x = x_0 + \Delta x_m + \alpha_m (x_0 - x_{0,m}) \quad (3)$$

Hourly future weather datasets from 2015 to 2100 were generated base on MIRCO3.2-MED GCM, whose predicting values were deemed and verified as acceptable against Taiwanese historical climate suggested by the study from Huang [2]. This model has also been suggested by Chan's study [3] and has been adopted in generating Hong Kong's future weather datasets. Furthermore, three future time slices (2020s, 2050s, and 2080s) were also produces via algorithms identical to those in generating TMYs suggested by Sandia Laboratory [4]. Once the future weather data were prepared, dynamic building simulation tools, EnergyPlus, was used to simulate a given typical residential apartment in studying its projected annual cooling energy consumption fluctuation in the three future time periods.

2.2 Comfort criteria

A hybrid-ventilation house is primary running in NV mode, whenever indoor thermal condition is experiencing overheating air-conditioning is used. Therefore, it's crucial to select an appropriate thermal comfort criteria to assess whether it is overheating of the indoor thermal conditions. An adaptive thermal comfort criteria suggested by ASHRAE Standard 55 has been widely used and recognized, thus it is adopted in this study for assessing and determining whether the mechanical cooling is in operation of the example residential building. From the definition of the adaptive thermal comfort model in ASHRAE 55, the optimum indoor thermal comfort operative temperature (Tc) is a function of monthly average outdoor temperature (Tom), and is given in below. The 80% acceptable comfort range is defined as Tc±3.5˚C.

$$T_c = 0.31 \times T_{om} + 17.8 \quad (4)$$

3. Results and discussion

3.1 Future climate change analysis

Hourly weather data points predicted with SRES A1B [5] scenario were superimposed on the psychrometric chart as figure 1. The figure illustrates areas of climatic distribution in four time slices (1993-2014 as 2000s, 2015-2040 as 2020s, 2041-2070 as 2050s, and 2071-2100 as 2080s). Hourly weather data points disperse towards higher temperature and higher humidity direction over times. Surprisingly, we observed that the lower temperature regions are also slightly shifted towards higher values over times. It indicates that an evident trend of global warming effect is occurring in Taiwan.

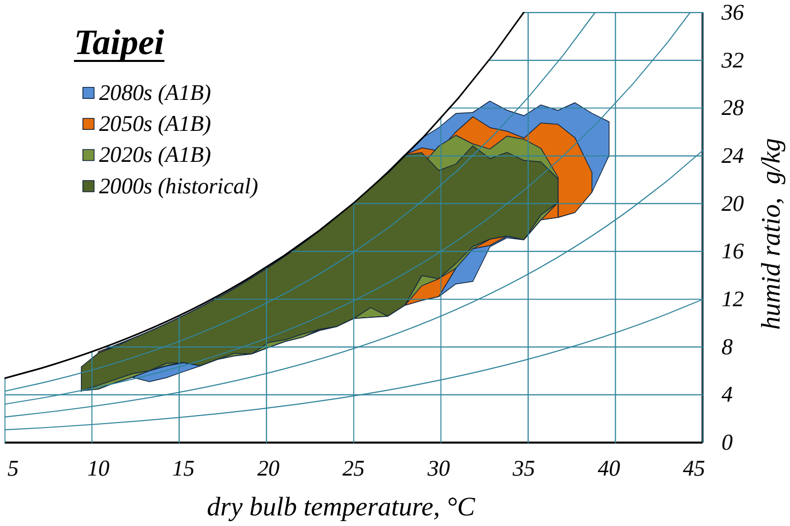

Fig. 1 Distribution areas of hourly weather condition in 2000s, 2020s, 2050s, and 2080s under A1B scenario.

3.2 The applicability of passive design strategies

The applicability of five passive design strategies for maintaining indoor thermal comfort are appraised against psychrometric chart, including passive solar heating (PS), natural ventilation (NV), high thermal mass (HM), high thermal mass and natural ventilation combined (HMV), and evaporative cooling (EC). These passive strategies and the applicable zones overlaid on psychrometric charts are originated from the early study by Givoni [6]. To have a more comprehensive view, zones of two active strategies, i.e. traditional heating and cooling, are also shown on the bioclimatic chart. The potential effective use of every strategies can be evaluated via superimposing 12 monthly climatic lines over psychrometric charts. The two end points of every monthly climatic lines represent the monthly average minimum temperature/relative humidity and the monthly average maximum temperature/relative humidity respectively. The ratio of the lines fall into a given passive design zone is the potential effective use of that given passive strategy. For not overcrowding the chart, only monthly climatic lines of 1993 and 2100 were illustrated in figure 2.

It is found that as climate changes, there is an evident increase in the ratio of mechanical cooling demand albeit there is unnoticeable decrease of the potential effective use of NV strategy. Take SRES A1B for example, while the potential effective use of NV decreases from 0.40 to 0.38, the ratio of the demand for mechanical cooling drastically rises from 0.24 to 0.36 from 2000s to 2080s. As illustrated in figure 3, 100 years of the potential effective use of passive design means of natural ventilation technique is decreasing as outdoor ambient temperature rises. A similar trend in the decreasing trend is also observed for the proportion of hours in comfort zone.

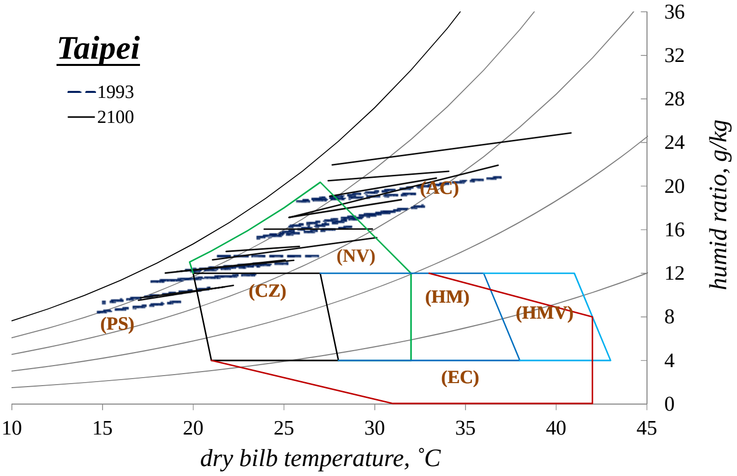

Fig. 2 Givoni's Bioclimatic chart for 1993 and 2100.

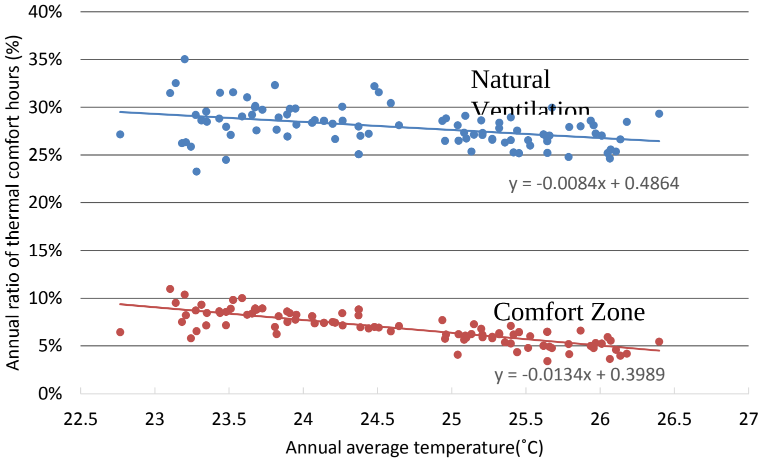

Fig. 3 Variation of the annual potential ratio of comfort zone and natural ventilation against outdoor temperature assessed from Bioclimate chart under SERS A1B

In comparison with the baseline case (1998-2013), for the future three time slices, the overheating frequencies slightly increase from today's 0.03% to 0.48%, 2.23%, and 5.39%, respectively for living room; and from 0.68% to 0.5%, 1.86%, and 4.15% for bedrooms. However, the growth rate of overheating severities exponentially increase by 210%, 1213%, and 3360% for living room; and are -34%, 299%, and 877% for bedrooms. It indicates that spaces using during daytime are much more vulnerable to overheating problems both in terms of occurrence probability and the severity in the future climate context, which may cause natural ventilation ineffective and need mechanical cooling to maintain indoor thermal comfort.

3.3 Cooling energy fluctuation due to climate change

The analysis results presented here have considered the people's acclimation effect in determining the use of mechanical cooling of the mixed-mode operating residential units. Cooling energy consumptions revealed in figure 4 are increasing in a drastic manner in the past 22 years and the future 86 years. The annual cooling energy consumption in different time slices of 2000s, 2020s, 2050s, and 2080s, are 35.1, 46.0, 55.8, and 63.9 kWh/m^{2}y accordingly. The average increasing ratios are 31%, 59%, and 82% correspondingly as compared to that in 2000s period. It suggests that there is a demand in building envelope remodeling by adaptive passive design means in mitigating the excessive cooling energy use.

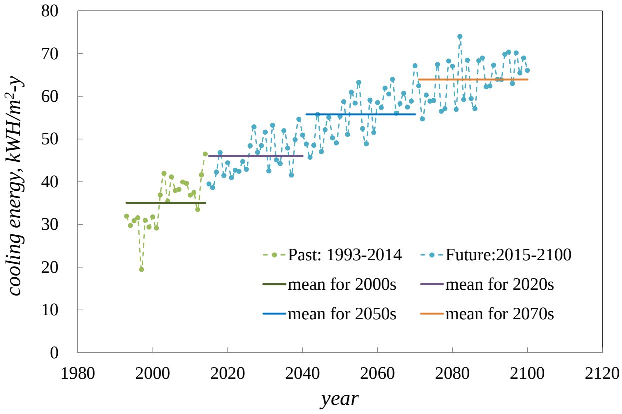

Fig. 4 The annual cooling energy of the example residential units under SRES A1B

4. Conclusions

1) Future hourly meteorological weather time series were constructed in this study to study the impact of the indoor thermal conditions and cooling energy use of residential buildings.
2) Adaptive thermal comfort model was employed to assessed the occupant's comfort conditions of a natural ventilated residential house in three future time slices (2020s, 2050s, and 2080s) as compared to the present climate, the results reveal that although the overheating occurrence frequencies were slightly increase, the overheating severities exhibit a rather dramatic increase.
3) The cooling energy usage trend was evaluated of a hybrid ventilated residential apartment, and revealed that an increment of the cooling energy by a magnitude of 31%, 59%, and 82% in three future time slices as compared to today's level was observed.
4) Future studies of this study may be formulating strategies and evaluate their potential effective abilities in counteract to the climate change.

Acknowledgment

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