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ORIGINAL ARTICLE

Effect of typical meteorological year selection on integrated daylight modeling and building energy simulation

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Abstract

The complete description of outdoor luminous and thermal environment is the basis for daylight utilization design with simulation tools. Nevertheless, Typical Meteorological Year (TMY) and generation method specifically developed for the energy simulation of daylight-utilized buildings is still unavailable currently. Luminous environment parameters have not been taken into consideration in existing TMY generation methods. In this study, the feasibility of existing TMY generation process has been examined. A generic office model implementing sided window daylighting is established. Historical meteorological data of Hong Kong from 1979 to 2007 have been collected and three existing weighting schemes are applied during the Typical Meteorological Month (TMM) selection procedures. Three TMY files for Hong Kong are generated and used to conduct integrated Climate-Based Daylight Modeling and building energy simulation. The result demonstrates that, on annual basis, the energy consumption results obtained from the generated TMY files are in good agreements with the long-term mean annual value. The maximum deviation of annual energy consumptions for the generated TMY files is only 1.8%. However, further analysis on monthly basis shows that all the three generated TMY files fail to fully represent the long-term monthly mean level. The maximum deviation of monthly energy consumptions for the generated TMY files can reach up to 11%. As the energy performance daylight utilization is subject to weather change, analysis on daily and monthly energy level is important, especially during design stage. The deficiency of existing TMM selection process and TMY generation method indicates the necessity to develop a corresponding typical weather data input with finer resolution for the energy simulation of daylight-related buildings.

Keywords Typical meteorological year, Building energy simulation, Climate-based daylight modeling, Daylight utilization

摘要

室外光环境和热环境的完整表征是利用模拟工具进行自然采光应用设计的基础，现阶段仍较为缺乏面向自然采光应用建筑能耗模拟所开发的典型气象年和生成方法，在现有典型气象年生成方法中未有纳入对光环境参数的考量。本研究考察了现有典型年生成方法对于自然采光能耗模拟的适用性，通过建立侧窗采光的办公建筑模型，利用所收集到的中国香港1979年至2007年的历史气象数据，在典型气象月筛选过程中采用三种加权方案，生成了三个典型气象年文件，用于进行基于气候的自然采光和建筑能耗模拟。结果表明，

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在年能耗水平上，使用生成的典型气象年文件所获得的能耗结果与长期平均年能耗数值较为一致，年最大偏差仅为1.8%。然而，针对月能耗结果的分析指出，使用所生成的三个典型气象年文件均不能获得全面代表长期月平均水平的能耗结果，月能耗最大偏差可高达11%。进一步分析指出，自然采光节能措施易受天气变化的影响，因此对其能耗性能水平进行日和月的评估将非常重要，尤其针对设计阶段。由于现有典型气象月筛选过程和典型气象年生成方法在此方面存在短板，有必要针对自然采光应用建筑的能耗模拟开发具有更精细时间尺度的典型气象输入数据文件.

关键词 典型气象年，建筑能耗模拟，基于气候的采光模拟，自然采光应用

1 Introduction

Making full use of renewable energy is one of the most reliable ways to achieve the energy efficiency within buildings. As a renewable resource and the most basic natural element, daylight has great potential in terms of energy efficiency to supplement and even replace indoor artificial lighting. Previous studies have found that 50% to 80% of lighting energy can be saved by using daylight linked control combined with daylight introduction through sided windows, and up to 40% of lighting and air conditioning energy can be reduced [1]. Mirza and Bergland identified that at least 1% of the electricity consumption can be saved nationally in Sweden and Norway through appropriately using daylight to supplement indoor lighting [2]. Moreover, sunlight is also an effective strategy to enhance occupants' thermal comfort, visual comfort, healthy and productivity [3]. Such great benefit has made daylight utilization the hot spot of energy-efficient research.

As exterior luminous and thermal environment can significantly influence the overall energy performance of air conditioning and lighting systems within buildings, the establishment of a positive cooperation among the building and its ambient environment is the key to improving building energy efficiency through daylight utilization. Owing to the sophistication of daylight-related study, integrated simulation tools have become indispensable for evaluating indoor daylight availability and energy performance of daylight-utilized design. The selection of feasible weather input data is the premise to generate solid simulation results, as the accuracy of building energy simulation is largely counted on the reliability of the input meteorological data [4]. Argiriou et al. generated a total of 17 Typical Meteorological Year (TMY) files with various weighting schemes and applied them in the energy simulations of different renewable energy systems [5]. The results identified that the feasible meteorological data for specific renewable energy systems, such as solar photovoltaic systems and solar panel heat collection systems, are different. The research also indicated that using non-corresponding meteorological data could cause distorted energy simulation results thus corresponding TMY file may need to be proposed for the simulation using specific energy-efficient measures.

Regarding to energy simulation of daylight-utilized building, the input meteorological data file should comprehensively represent the characteristics of on-site thermal and luminous environmental parameters. Their simulation results should reflect the long-term average level of energy performance in daylight-utilized building in order to better evaluate the energy-efficient outcome of the studied daylight measure. Traditional static daylight calculation approach based on Daylight Factor (DF) are conducted with a fixed sky type (for example, CIE overcast sky), regardless of the real sky condition. The effect of different building location, simulation timing, and input weather data cannot be reflected by DF model. Despite DF is still the most widely used performance metric and has been adopted as an important reference for indoor daylight evaluation, its limitations have been widely questioned in recent years [6]. With the development of dynamic daylight metrics (such as Useful Daylight Illuminance [7, 8], Daylight Autonomy [9] as well as Continuous Daylight Autonomy [10], feasibility of input meteorological data for Climate Based Daylight Modeling (CBDM) become a new concern.

Currently, researches of meteorological data files considering luminous environment is quite limited. Markou et al. attempted to generate Daylight Reference Years (DRYs) with observed luminous meteorological record in Athens and Bratislava's spanning 5 to 8 years [11]. Meteorological parameters including relative sunshine duration, diffuse horizontal illuminance, global horizontal illuminance, zenith luminance, diffuse horizontal irradiance, global horizontal irradiance, linke's turbidity factor and luminous turbidity factor have been considered. TMY generation methods of modified Sandia method, the Festa-Ratto method, along with the Danish method were applied. Nevertheless, luminous environment parameters used in that case are often unavailable in practice. Meanwhile thermal meteorological parameters were not considered in the Typical Meteorological Month selection process. The connection between weather variables and building energy consumption was not taken into consideration. Thus, the generated DRYs are not feasible for the energy simulation of daylight-utilized buildings. Wong et al. generated Typical Reference Year (TRY) and TMY files for Hong Kong with nine meteorological parameters considered, namely total solar radiation, daily minimum, maximum and average values of dew point temperature, average and maximum wind speed, and dry bulb temperature. With these files, the distribution of sky conditions derived from the generated TMY and TRY were also analyzed [12]. Bellia et al. investigated the impact of weather data files on Climate-based Daylight Modeling [13]. The TRY and IWEC files of Nancy, Copenhagen, Rome, Milan, London, along with the meteorological files generated by Satel-Light and Meteonorm, were used to calculate daylight metrics. The results suggested that TRY input would lead to lower calculation values while the results of the other three meteorological year files were closer to the long-term average. However, as only northern exterior window was set in the building model and direct illuminance was excluded, the conclusion was with certain limitations and could not completely resolve the concerns.

As luminous environmental parameters are not considered during selection process, existing TMY selection method may not be able to comprehensively reflect the overall impact of outdoor thermal and luminous weather on the energy consumption of daylight-utilized building. In this paper, effect of weather data file selection is examined through integrated Climate-Based Daylight Modeling and building energy simulation. Different TMY files are generated with different weighting schemes during the Typical Meteorological Month (TMM) selection. Not only the energy consumption of lighting system, but also the energy consumption of air conditioning system and their overall performance are extracted. Energy performance predicted from the generated TMY files are compared with the long-term mean performance. Energy consumption of both annual and monthly levels are examined.

2 Methodology

The Typical Meteorological Year (TMY) file, which contains 8760 hourly meteorological datasets representing the prevailing outdoor environment, has been widely used in dynamic energy simulation [14]. There has been no general agreement on the generation method of TMY. While various generation methods of TMY follow different process in certain details, the generation process of TMY could be briefly summarized into three steps: (i) collection of raw data, (ii) Selection of Typical Meteorological Month (TMM) and (iii) Connection of TMMs. The weighting scheme applied in TMM selection is the core part within the whole generation process.

Weighting scheme consists of two parts: the considered meteorological parameters and their weighting factors. Among all the meteorological contained in TMY file, only a small number of these parameters will be considered during the TMM selection. The considered meteorological parameters are expected to reflect the focusing of the studied system on climatic environment. The relative importance of these meteorological parameters is indicated by their weighting factors. Therefore, the weighting scheme needs to be adjusted according to the type and feature of the studied energy system [15]. Petersen and Svendsen also found that for renewable energy systems, the weighting factors used in the generation of a TMY file is critical [16].

By reviewing the weighting schemes of existing generation TMY methods in details [17–39], these alternative weighting schemes are found to share the following common features: (i) Mainly focused on thermal meteorological factors, such as dew point temperature, dry bulb temperature, wind, relative humidity and solar radiation. Luminous meteorological parameters have not been taken into consideration. (ii) Solar radiation parameters are prior to other considered meteorological parameters in weighting factor assignment. Weighting factor of average or daily total horizontal solar radiation are usually assigned between 40% and 50%. This is because that most TMY files are initiated for solar energy system which largely depends on the daily total amount of solar radiation. (iii) Diffuse and direct solar distinction is not considered for solar radiation. For now, due to the lack of long-term measured luminous environment data, daylight-related study often adopts indirect description of luminous environment. Illuminance related parameters are derived with luminous efficacy model using available irradiance data. The characteristics of illuminance parameters daily profile cannot be only defined through the daily total amount or average solar radiation.

To identify the effect of these deficiencies of existing TMM selection process and TMY generation method on the prediction of daylight-utilized energy performance, a generic office model implementing sided window daylight is established to conduct integrated Climate-Based Daylight Modeling and building energy simulation. With the building mode, a total number of 32 annual simulations are carried out, including:

- 29 simulation runs using the annual historical meteorological data of Hong Kong from 1979 to 2007.
- 3 simulation runs using the generated TMY files.

Energy consumption data of individual calendar years are extracted and used to calculate long-term mean performance. The closeness of energy consumption data obtained from the generated TMY files to the long-term mean performance is compared.

2.1 Generation typical meteorological year files

The generation of TMY files is based on the Sandia method. Historical meteorological data of the Hong Kong

Observatory from 1979 to 2007 are employed as source data. Available meteorological parameters include hourly datasets of relative humidity, the dry bulb temperature, wind speed, dew point temperature, horizontal total solar radiation, horizontal diffuse solar irradiance and normal beam solar irradiance.

For each calendar month, the closeness between the monthly and the long-term cumulative distribution function for each of the considered meteorological parameters are calculated with Eq. 1:

$$FS_x(y,m) = \frac{1}{N}\sum_{i=1}^{N}\left|CDF_m(x_i) - CDF_{y,m}(x_i)\right| \quad (1)$$

where $FS_x(y,m)$ is the Filkenstein–Schafer (*FS*) statistic of the meteorological parameter x for the year y and the month m, $CDF_{y,m}$ is the short-term *CDF* value of the daily meteorological parameter x for the year y and the month m, CDF_m is the long-term *CDF* value of the daily meteorological parameter x for month m, and N is the number of bins.

Table 1 Weighting schemes for TMM selection

Parameters	Weighting factors		
	WS1	**WS2**	**WS3**
Dry bulb temperature maximum	5/100	1/24	1/24
Dry bulb temperature minimum	5/100	1/24	–
Dry bulb temperature average	30/100	2/24	–
Dew point temperature maximum	2.5/100	1/24	1/24
Dew point temperature minimum	2.5/100	1/24	–
Dew point temperature average	5/100	2/24	–
Wind speed maximum	5/100	2/24	11/24
Wind speed average	5/100	2/24	–
Total solar radiation	40/100	12/24	11/24

The calculated result of each parameter is multiplied by the corresponding weighting factors and summed together. The weighting sum (WS) value is given by Eq. 2:

$$WS(y,m) = \sum_{x=1}^{M} FS_x(y,m) \cdot WF_x \quad (2)$$

where M is the number of considered meteorological parameters, WF_x is the weighting factor for parameter x, $WS\ (y,m)$ is the weighting sum for the year y and the month m. The candidate month with the smallest WS is selected as the TMM for that month.

Three different weighting schemes are accepted in TMM selection process. Table 1 lists the considered meteorological parameters and their weighting factors in the three different weighting schemes, of which WS1 and WS2 have been conventionally used in the generation process of the TMY and the IWEC file series [40, 41], respectively, while WS3 is proposed by Lv and developed mainly for wind power and solar energy application [21].

Table 2 shows the three TMY files generated from different weighting schemes. The typical weather data files generated by WS1, WS2 and WS3 are respectively labeled as TMY_1, TMY _2, and TMY _3. Partially overlapped can be found among the TMMs selected by the three weighting schemes. TMY_1 has five TMMs overlapped with TMY_2 (May, August, September, October, and November) and three TMMs overlapped with TMY_3 (August, November, and December). TMY_3 overlapped with TMY_2 in TMMs of February, August, and November. Although the TMMs selected by the three weighting schemes are partially overlapped, the three resulted TMY files are still quite different and only overlap in August and November, which are respectively selected from 2002 and 1989.

Since the selected twelve TMMs may come from different years, smoothing method is adopted to avoid the disconnection at the boundary between two adjacent months. 6 h data of both before and after the transition

Table 2 TMMs selected by different weighting schemes

Month	TMY_1	Weighting sum	TMY_2	Weighting sum	TMY_3	Weighting sum
1	1995	0.0472336	2004	0.04632651	1999	0.03618375
2	1997	0.06020359	2000	0.05293068	2000	0.0309018
3	2003	0.03841906	1998	0.04011708	1980	0.04036787
4	1986	0.04682826	1980	0.04845325	2003	0.04206756
5	1997	0.04010616	1997	0.0436167	1998	0.04037559
6	1990	0.03930837	1991	0.04146673	1992	0.04050272
7	2000	0.04063583	1986	0.0357692	1996	0.03238058
8	2002	0.03772398	2002	0.04099051	2002	0.03331187
9	1982	0.03498207	1982	0.04158585	1989	0.03838576
10	1984	0.04024907	1984	0.04327664	1987	0.03774977
11	1989	0.04190997	1989	0.03874508	1989	0.04050553
12	2000	0.05470126	1993	0.05077893	2000	0.04480786

timing of adjacent months are processed. With cubic spline interpolation function, parameters of wet bulb temperature, dry bulb temperature as well as wind speed are directly smoothed. Relative humidity is calculated later via the psychrometric relationship with dew point temperature and dry bulb temperature after smoothing.

Conventionally, February 29th is not contained within TMY data file. As February 29th is not contained in the leap years of source data in this study, either, no special treatment has been carried out for the leap year during TMM selection and February contains days from February 1st to February 28th.

Annual meteorological data of Hong Kong from 1979 to 2007, together with the three selected TMY data files are used to generate weather files of EPW format through software ELEMENT. A total number of 32 annual weather data files are produced for the following simulations.

2.2 Simulation configuration

An integrated daylight modeling and building energy simulation are conducted. Radiance is implemented as daylight simulation engine to conduct Climate-based Daylight Modeling, while EnergyPlus is employed as simulation engine for energy simulation. Radiance first performs gridded daylight simulation under actual condition introduced by weather input data file, and then transfers the daylight level at each reference point to EnergyPlus. With the received result, EnergyPlus calculates the dimming degree of indoor lighting system and applies in the energy consumption simulation. The coupling of Radiance and EnergyPlus is realized through OpenStudio V2.1.0.

A generic office building floor implementing sided-window daylight is established as the building model. A schematic diagram of the office building model can be found in Fig. 1. The medium building model used is a square (30 m × 30 m) office floor with floor-to-floor height of 4.5 m. The window-to-wall ratio (WWR) of exterior walls is 0.5. The heights of window and window sill are 2.25 m and 1.0 m, respectively. Conventional zoning strategy is applied with a perimeter zone depth of 4 m. The floor is divided into one core zone and four perimeter zones, which are defined as south zone, north zone, east zone and west zone according to the orientation. Table 3 summarizes the configuration of building energy simulation.

Each exterior window is equipped with interior blind. The Interior blind devices will be activated when the incident radiation exceeds 100 W/m^2, and the slat angle will adjust to block the direct solar radiation. Otherwise, the shading devices are retracted and do not function.

As Hong Kong is a subtropical city as cooling dominant, only cooling mode is considered in the simulation. To avoid the simulation results affected by the characteristics of the selected air conditioning system, the indoor cooling load is calculated using the ZoneHVAC: IdealLoadsAir System module in EnergyPlus. When the indoor temperature is above the cooling set-point, air-conditioning system will start cooling. To avoid the discomfort at arrival, space cooling is set to start 1 hour ahead, namely the air conditioning system operates from 7 am to 6 pm on weekdays.

To improve the accuracy of daylight modeling, fine mode employed in Radiance. For each perimeter zone,

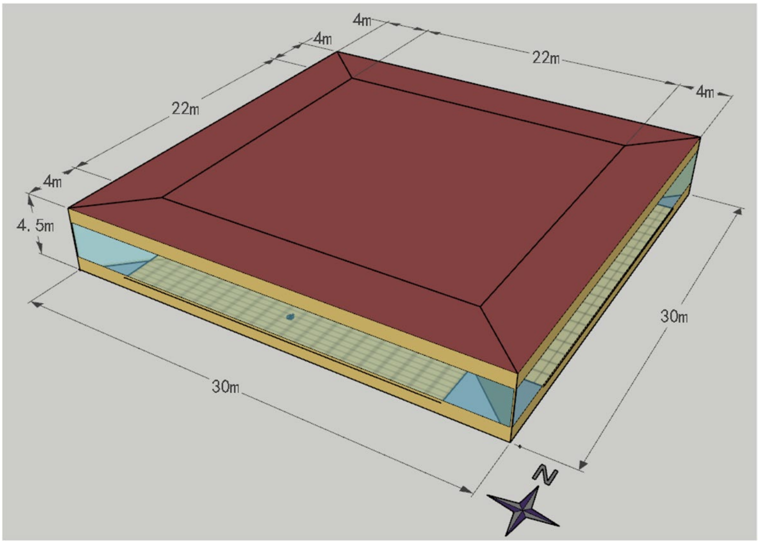

Fig. 1 A schematic diagram of the office building model

Table 3 Configuration of building energy simulation

Properties of opaque envelope		**Properties of exterior window**	
U-value of exterior wall	1.0 W/m^2·K	Glazing type	Double low-E
U-value of floor	0.5 W/m^2·K	U-value	1.4 W/m^2·K
U-value of roof	0.88 W/m^2·K	SHGC / VT	0.48 / 0.7
Indoor design parameter		**Properties of shading**	
Operation time	Weekday	Shading type	Interior blind
	8:00–18:00	Slat thickness	1 mm
Lighting power density	20 W/m^2	Slat width	25 mm
Illuminance target	500 lx	Solar radiation reflectance (beam/diffuse)	0.5/0.5
Equipment power density	20 W/m^2		
Occupant density	4 m^2/person		
Occupant heat dissipation	130 W/ person	Visible reflectance (beam/diffuse)	0.5/0.5
Air change rate	30 m^3/ person·h		
Cooling set temperature	24 °C		

one illuminance map is set on a horizontal plane 1 m above ground. The depth and length of the illuminance map are 4 m and 22 m, respectively. Each illuminance map is meshed into 22 parts with 1 m as interval along the length direction, and 8 parts with 0.5 m as interval along the depth direction. There are a total of 176 grids ($1\,m \times 0.5\,m$) on each illuminance map.

The dimming degree of indoor lighting within each perimeter zone is derived with the daylight reference point placed on the illuminance map. Each daylight reference point is positioned 2 m inward from the exterior wall and centered along the perimeter depth on the corresponding illuminance map. Target value of illuminance at the daylight reference point is 500 lx. If the illuminance value at the daylight reference point reaches over 500 lx by daylight alone, the artificial lighting in the zone will be set as completely switched off, and only daylight is used for indoor lighting. Otherwise, artificial lighting will be switched on under a linear dimmable control to ensure the targeted illuminance at the daylight reference point.

Simulation is conducted with a run period from January 1st to December 31st. The outputs of indoor cooling load and lighting energy consumption of each perimeter zone are extracted. As the core zone is barely affected by daylight, only outputs of perimeter zones are taken into accounted. An overall COP of 3 is used to convert indoor cooling load into the energy consumption of air-conditioning system. The overall energy consumption of lighting and air-conditioning systems is then calculated by summing the energy consumption values of both lighting and air conditioning systems. With the extracted results, the long-term annual and monthly average of lighting energy consumption, indoor cooling load, and overall energy consumption are calculated for subsequent analysis.

3 Results and discussion

3.1 Energy consumption data of individual calendar years and the long-term mean

Figures 2, 3 and 4 show the profiles of monthly maximum and minimum energy consumption parameters, which represent the fluctuation of monthly values between different years over the long-term. It is found that the fluctuation of monthly air-conditioning energy consumption is obviously larger than that of lighting energy consumption. The fluctuation degree of monthly overall energy consumption is between the fluctuations of lighting energy consumption and air-conditioning energy consumption.

The profiles of the maximum and minimum monthly energy consumption values generally follow the trend of the long-term mean level of the 29 years. It can be found that the air-conditioning energy consumption peaks during May to October, so as the overall energy consumption.

For each calendar month, the values of energy consumption from different years have fluctuated greatly. Compared with the long-term mean level, the largest monthly deviation of lighting energy consumption within the 29 years is 181 kWh, 25.8% higher than the corresponding month's long-term mean level of 702 kWh. For air-conditioning energy consumption, the largest monthly deviation value occurs in October (927 kWh), while the largest monthly deviation percentage occurs in February (−56.9%). The largest monthly deviation of overall energy consumption also occurs in October and the value is 873 kWh, 27.7% higher than the corresponding month's long-term mean level of 3153 kWh.

On annual basis, the discrepancies between individual calendar year and long-term mean are ranging from −2% to 5% for lighting energy consumption, −8% to 12% for

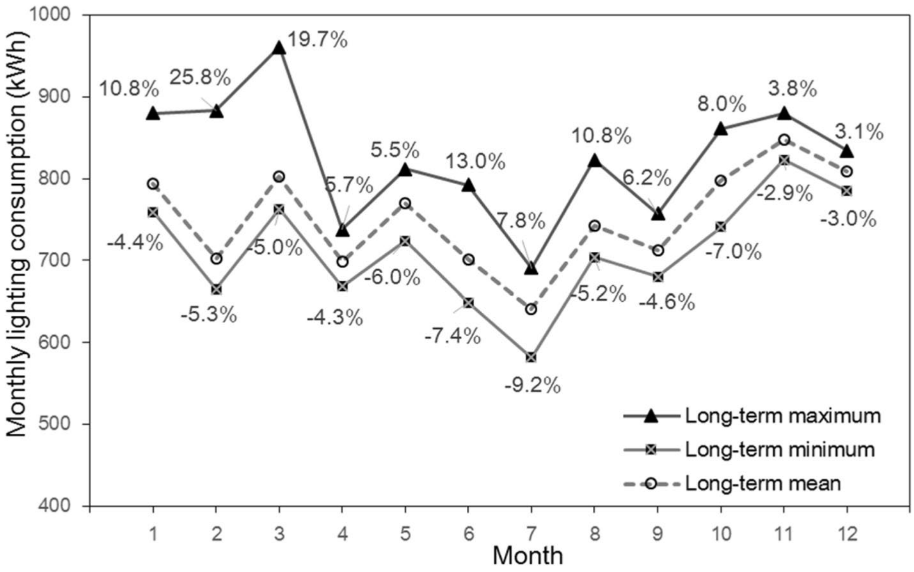

Fig. 2 The profile of monthly maximum, minimum and mean lighting energy consumption

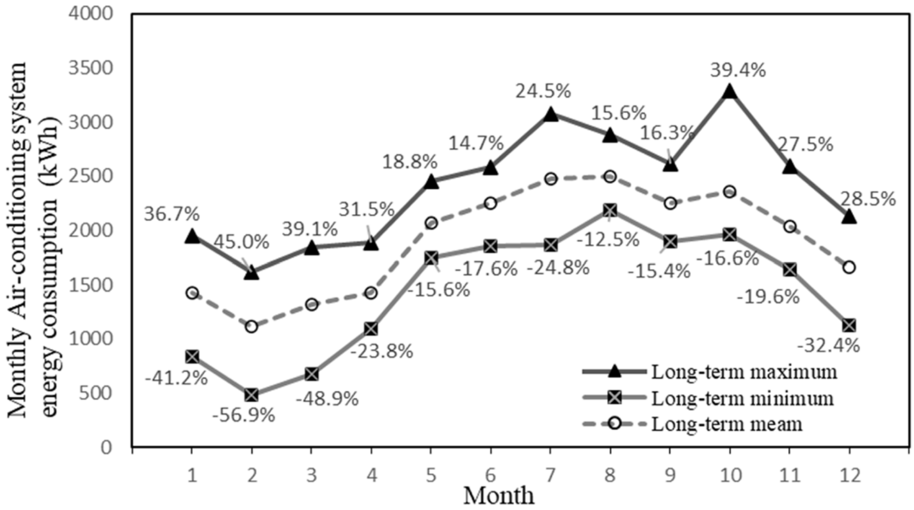

Fig. 3 The profile of monthly maximum, minimum and mean air-conditioning energy consumption

air-conditioning energy consumption, and − 5% to 8% for overall energy consumption. The largest deviated values within the 29 years are 467 kWh for lighting energy consumption, 2687 kWh for air-conditioning energy consumption, and 2619 kWh for the overall energy consumption.

The comparison between individual calendar year and long-term mean reveals that selecting a random year's weather data as input cannot generate a representative annual result of daylight-utilized energy performance. Moreover, as the energy consumption values of each calendar month have a large fluctuation range among different years, the selection of Typical Meteorological Month is crucial for the accurate prediction of monthly energy consumption. Unexpected bias may be introduced by the unfeasible assignment of weighting scheme.

3.2 Energy performance predicted with TMY files and long-term mean

Table 4 shows a detailed comparison of energy consumption predicted with the three TMY files and long-term mean. It can be found that, on monthly basis, the monthly lighting energy consumption prediction obtained from the generated TMY files are close to the long-term mean, and the maximum deviation is 5.3%. Figure 5 further

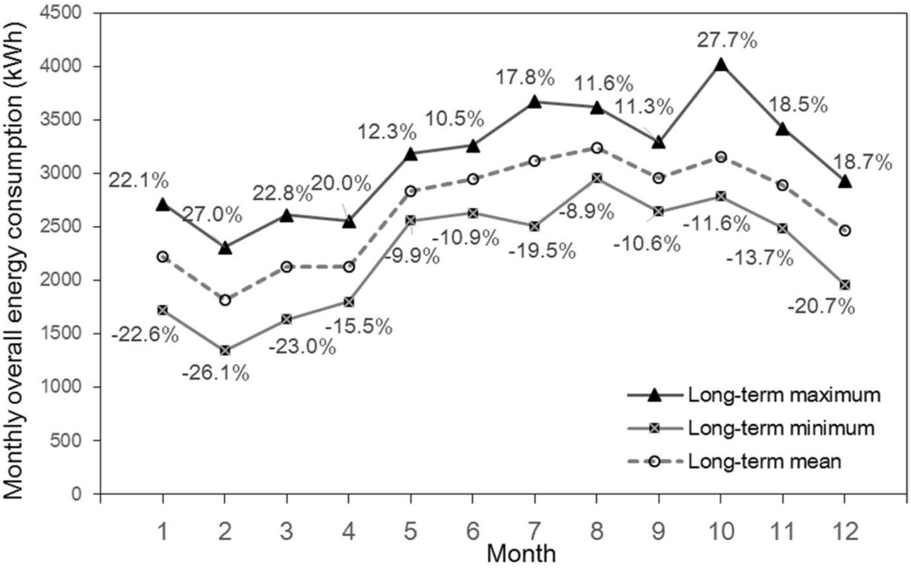

Fig. 4 The profile of monthly maximum, minimum and mean overall energy consumption

illustrates the profiles. For monthly air-conditioning energy consumption, the predicted accuracy of the generated TMY files is unstable. Figure 6 shows the monthly air-conditioning energy consumption of the generated TMY files and long-term mean. For each TMY files, the predicted values of air-conditioning energy consumption are consistent with the long-term mean value in some TMMs. For example, the monthly air-conditioning energy consumption values of nine TMMs in TMY_1 and ten TMMs in TMY_2 deviate from the long-term mean value by no more than 5%. Similarly, the monthly air-conditioning energy consumption values of seven TMMs in TMY_3 deviate from the long-term average value no more than 5%.

However, for some other months, the deviation of air-conditioning energy consumption from the long-term mean level is significant. In the February, April, June, July, September and December of TMY_3, large discrepancies of − 6.8%, 8.4%, − 10.8%, 6.4%, 5.1% and − 7.4%, are found compared with the long-term mean monthly air-conditioning energy consumption level. Moreover, the trend of TMY_3 profile is inconsistent with that of the long-term mean, either. Although the profiles of TMY_1 and TMY_2 generally follow the long-term mean quite closely, they show large discrepancies from the long-term mean monthly levels of air-conditioning energy consumption in some certain months. For TMY_1, deviations of − 11.3%, 11.1%, and − 7.4% can be found in January, April, and December, respectively. For TMY_2, deviations of January, February, and April are − 9.2%, − 6.8%, and − 6.9%, respectively.

The maximum deviation degree between the generated TMY files and the long-term mean levels is 11.3% for TMY_1, 9.2% for TMY_2, and − 10.8% for TMY_3. The months with maximum deviation are all within the conventional cooling season of Hong Kong, which is from March to November. The predicted values of overall energy consumption, obtained from the generated TMY files, also showed a large deviation in the above-mentioned months. Their deviation range is affected by the combined effect of the natural and artificial lighting, as well as air-conditioning.

The above analysis present that, for the three generated TMY files, there are significant deviations between the predicted energy consumption and long-term mean value within a number of months, with the maximum deviation up to 11%. However, in terms of annual level, the predicted energy consumption values from the three TMY files are very close to the long-term mean annual performance. The deviation degrees between the generated TMY files and long-term mean range from 0.1% to 0.6% for annual lighting energy consumption, 0.4% to 1.8% for annual air-conditioning energy consumption, and 0.1% to 1.3% for annual overall energy consumption.

4 Conclusion

The Typical Meteorological Year data file is critical to the modeling of building energy performance, especially for daylight-utilized building system required Climate-Based Daylight Modeling. Based on the historical hourly weather data between 1979 and 2007, three existing weighting schemes are applied during the TMM selection procedures. Three TMY files for Hong Kong are

Table 4 Deviation between the simulation results obtained from the generated TMY files and the long-term mean level

Parameter			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMY_1	Lighting energy consumption	kWh	794	679	795	692	773	703	617	751	708	799	843	817
		Deviation	0%	−3.3%	−1.0%	−0.9%	0.4%	0.3%	− 3.7%	1.1%	−0.7%	0.3%	−0.6%	1.0%
	Air-conditioning energy consumption	kWh	1267	1102	1350	1589	1984	2289	2437	2498	2195	2448	2077	1538
		Deviation	−11.3%	−1.3%	2.1%	11.1%	−4.1%	1.8%	−1.5%	0.1%	−2.3%	3.9%	1.9%	−7.4%
	Overall energy consumption	kWh	2061	1781	2145	2281	2757	2992	3054	3249	2903	3247	2920	2355
		Deviation	−7.2%	−2.1%	0.9%	7.2%	−2.9%	1.4%	−1.9%	0.3%	−1.9%	3.0%	1.2%	−4.7%
TMY_2	Lighting energy consumption	kWh	817	665	786	709	773	704	654	751	708	799	843	797
		Deviation	2.9%	−5.3%	−2.1%	1.6%	0.4%	0.4%	2.0%	1.1%	−0.7%	0.3%	−0.6%	−1.5%
	Air-conditioning energy consumption	kWh	1296	1041	1364	1331	1984	2287	2368	2498	2195	2448	2077	1595
		Deviation	−9.2%	−6.8%	3.2%	−6.9%	−4.1%	1.7%	−4.3%	0.1%	−2.3%	3.9%	1.9%	−4.0%
	Overall energy consumption	kWh	2113	1706	2150	2040	2757	2991	3022	3249	2903	3247	2920	2392
		Deviation	−4.9%	−6.2%	1.2%	−4.1%	−2.9%	1.4%	−3.0%	0.3%	−1.9%	3.0%	1.2%	−3.2%
TMY_3	Lighting energy consumption	kWh	799	665	812	672	772	724	623	751	702	788	843	817
		Deviation	0.6%	−5.3%	1.1%	−3.7%	0.3%	3.3%	−2.8%	1.1%	−1.5%	−1.1%	−0.6%	1.0%
	Air-conditioning energy consumption	kWh	1447	1041	1333	1551	2060	2006	2632	2498	2361	2425	2077	1538
		Deviation	1.3%	−6.8%	0.8%	8.4%	−0.4%	−10.8%	6.4%	0.1%	5.1%	2.9%	1.9%	−7.4%
	Overall energy consumption	kWh	2246	1706	2145	2223	2832	2730	3255	3249	3063	3213	2920	2355
		Deviation	1.1%	−6.2%	0.9%	4.4%	−0.2%	−7.5%	4.5%	0.3%	3.5%	1.9%	1.2%	−4.7%

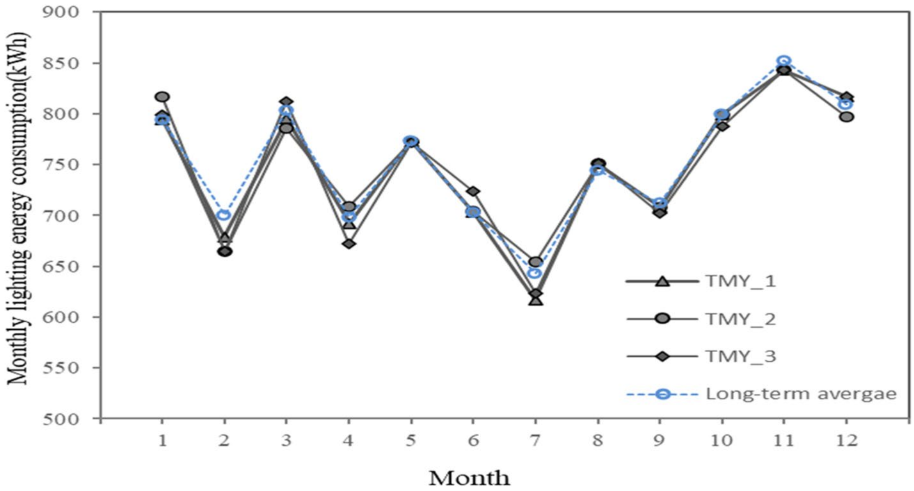

Fig. 5 The profile of monthly lighting energy consumption

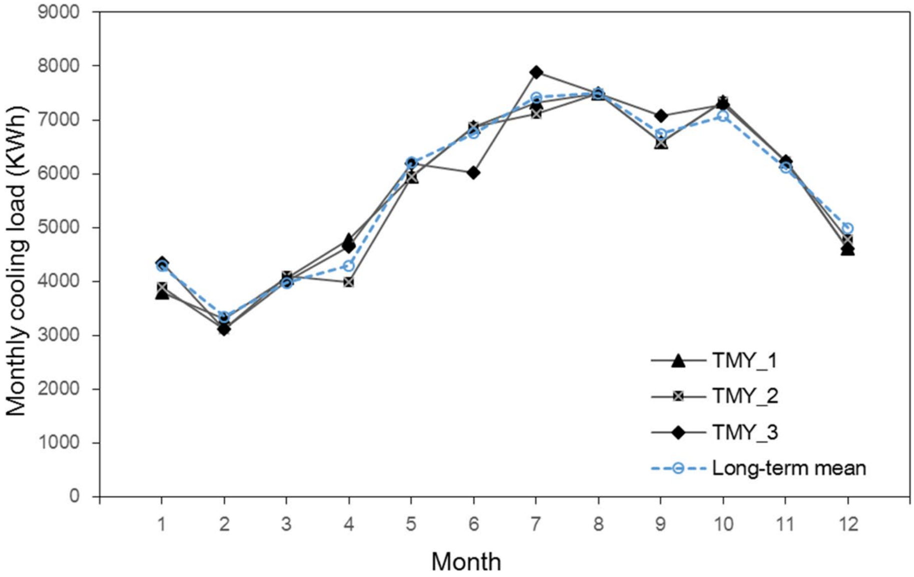

Fig. 6 The profile of monthly air-conditioning energy consumption

generated accordingly. The three generated TMY files are used to conduct Climate-based Daylight Modeling and building energy simulation. It is found that the energy consumption results obtained from the generated TMY files are in good agreements with the long-term mean performance on annual basis. The maximum deviation of annual energy consumption for the generated TMYs is only 1.8%, which indicates that the three generated TMY files can well indicate the prevailing energy performance in daylight-related building energy simulation in Hong Kong on annual level.

Further analysis on monthly basis shows that, energy performance predicted from the generated TMY files all contain certain months that show large deviation from the long-term mean performance. The maximum deviation of monthly energy consumption for the generated TMY file can reach up to 11% for the corresponding month. This result suggests that all the three generated TMY files fail to fully predict the long-term mean level when month is applied as analysis window. Moreover, as the comprehensive evaluation of daylight-utilized energy performance involve the energy performance of both lighting and air-conditioning systems within buildings, the generated TMY files also fail to accurately predict the monthly energy performance of the lighting, air conditioning and their overall performance at the same time.

The deficiencies in present the monthly energy performance suggest that subsequent study are needed to generate feasible weather input data specifically for the daylight-utilized building. As the energy performance daylight utilization is subject to weather change, daylight and thermal integrated simulation with finer resolution such as daily and monthly level is essential and important, especially for decision making during design stage. In fact, it is quite difficult to achieve based on the exiting TMM selection process and TMY generation methodology, as it was originally proposed to present the average level on annual basis. Additionally, continuous historical meteorological data records spanning a long time period are needed as raw data during the process of TMY generation. As these data are no readily available, it is common to find that some TMY files are generated based on less fresh data and may cause insufficient timeliness. As latest technology such as satellites and IoT devise develop, researchers may be able to move away from using TMY in the future and swing to apply weather dataset derived from real-time multi-source data with finer resolution for daylight-related building. This study shows that this swing is necessary.

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Authors' contributions
Data curation: Jingting Sun; Methodology: Jingting Sun; Formal analysis and investigation: Jingting Sun; Writing - original draft preparation: Jingting Sun; Writing - review and editing: Zhengrong Li, Cui Li, Xiwen Feng; Funding acquisition: Zhengrong Li; Supervision: Zhengrong Li; Project administration: Zhengrong Li. The author(s) read and approved the final manuscript.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
Jingting Sun is one of the Managing Editors for ***Low-carbon Materials and Green Construction*** and was not involved in the editorial review, or the decision to publish this article. All authors declare that there are no other competing interests.

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