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Analysis of Typical Meteorological Year selection for energy simulation of building with daylight utilization

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Abstract

Selecting suitable weather data is the premise of getting valid conclusion from building energy simulation. By analyzing the generation process of Typical Meteorological Year (TMY) , this paper points out that existing well-accepted TMY generation methodologies mainly emphasis the thermal aspect of climatic environment during their typicality selecting process. Light aspect has not been taken into consideration. A case study is carried out to explore whether there would be a divergence of conclusion when conducting daylight-related simulations with different TMY data. Performance metrics including Daylight Factor (DF), Daylight Autonomy (DA), Useful Daylight Index (UDI) and daylight illuminance distribution have been compared. The result indicates that for static metric as DF, the variation between using different TMY data is insignificant. However, for dynamic metrics such as DA, UDI and illuminance distribution, the divergence is obvious. Researchers are suggested to take caution of this effect when comparing simulation conclusions from different studies.

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Keywords: Typical Meteorological Year; Daylight utilization; Building energy simulation

Nomenclature

TMY	Typical Meteorological Year
DF	Daylight Factor, %
DA	Daylight Autonomy, %

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UDI	Useful Daylight Index, %

Introduction

Serving as an indispensable decision making tool, building energy simulation has been widely applied for its capacity of capturing dynamic performance of various building systems and predicting the outcome of energy saving strategies. As well acknowledged, the validity of simulation could be significantly influenced by the accuracy of inputs. Working as the exterior boundary condition in building simulation, outdoor climate condition could affect the simulation result directly. Therefore, as one essential step at the very first beginning of any simulation studies, selecting a suitable weather data file is the premise of getting valid conclusion resulted from building energy simulation

Climatic environment is characterized by its high randomness and uncertainty. Value of the same weather parameter at the equal moment could vary dramatically between different years. As a result of these features, simply applying the field measured values of one single calendar year as the climate condition in simulation setting is with inherent weakness and subject to be challenged for the lack of representativeness. The invention of Typical Meteorological Year (TMY) provides a solution to this problem and has been broadly accepted within the near decade.

Rather than a simple list of field measured data of one calendar year, TMY is a statistical year consisting 12 typical meteorological months (TMM) basing on the field measurement ranging over decades (usually around 30 years). The generation process of TMY file for a specific location is quite sophisticated and requires series of mathematical process. So far there has been no general agreement on the generation method of TMY. Various methods have been developed including Sandia method [1], Danish method [2], Festa-Ratto method [3], Crow method [4], Miquel-Bilbao method [5], and Gazelae-Mathioulakis method [6].

The generation of TMY could be generally summarized into three steps: raw data collection, typicality selection and TMM connection. Each step also contains a number of detailed procedures. Different choice made in every detail would result a different version of TMY, thus the TMY for one specific location is not unique. Detailed comparison between these methods could be found in reviews done by Skeiker [7], Janjai and Deeyai [8].

Table 1.Weighting schemes in various TMY methods

Weather index	TMY* [1]	TMY2 [9]	IWEC	SWERA	CSWD**
Maximum dry bulb temperature	1/24	1/20	5/100	1/24	2/16
Minimum dry bulb temperature	1/24	1/20	5/100	—	1/16
Mean dry bulb temperature	2/24	2/20	30/100	—	1/16
Maximum dew point temperature	1/24	1/20	2.5/100	1/24	—
Minimum dew point temperature	1/24	1/20	2.5/100	—	—
Mean dew point temperature	2/24	2/20	5/100	—	—
Maximum wind speed	2/24	1/20	5/100	11/24	—
Mean wind speed	2/24	1/20	5/100	—	1/16
Total horizontal solar radiation	12/24	5/20	40/100	11/24	8/16
Direct normal solar radiation	—	5/20	—	—	—

*Remark: TMY here is a narrow sense representing the Typical Meteorological Year generated with Hall's (1978) method. * *Remark: The CSWD method also includes 'mean surface temperature (1/16)' and 'mean water vapor pressure (2/16)'.

Actually the non-uniqueness is not only the result of different procedures during generation, but also the requirement of different research subjects. Although one TMY file contains a number of climatic factors, only a small amount of these factors have been taken into consideration during the typicality selection. The climatic factors participating typicality selection and their weightings are determined corresponding to the type and feature of the studied energy systems.

Different energy systems focus on different aspects of climatic environment. For example, solar energy system considers solar radiation factor more important than wind energy system. Therefore different weighting schemes are adopted to generate TMY for different energy systems. Table.1 lists the weighting schemes in some TMY methods. Most of existing well-accepted TMY files focused on the thermal aspect of climatic environment during their typicality selecting process. This may be sufficient when air conditioning system is the main concern, however, simulation for buildings utilizing daylight technologies requires more. Building with daylight utilization takes external illumination from outdoor environment as available source to supplement indoor artificial lighting system. So far there is no TMY file specifically generated for the energy simulation of building with the consideration of daylight utilization together with thermal aspect.

To fill this gap, a comprehensive study has been carried out including: (1) Analyze the consistence of conclusion resulted from using different existing TMY files in daylight simulation. (2) Compare the results of daylight simulations conducted with existing TMY and long-term measurement weather data. (3) Develop a new generation methodology for TMY used in simulation related to daylight utilization. This paper presents the first part of the above mentioned study.

2. Method

Three different TMY data files for four cities (Kunming, Shanghai, Beijing and Harbin) were deployed in the case study. These TMY data (CSWD, SWERA and IWEC, as listed in Table 2) could be easily accessed and have been frequently used nowadays. Daysim was used as the daylighting analysis tool to conduct annual simulations.

It is worth noted that the four cities are selected from four climatic regions of China. In fact, the division of climatic regions of China includes five types. Due to the SWERA data file of the hot summer and warm winter region is unavailable. Only cities from the other four regions were applied in this study.

Table 2.Sources of TMY data

TMY data	Original meteorological data source
Solar and Wind Energy Resource Assessment (SWERA)	1973-2002 period of record with data obtained from US Natural Resource Ecology Laboratory (NREL)
International Weather for Energy Calculations (IWEC)	Up to 18 years (1982-1999) of DATSAV3 hourly weather data originally archived at the U. S. National Climatic Data Center （Summarized by ASHRAE）
Chinese Standard Weather Data (CSWD)	1971-2003 period of record with data obtained from China Meteorological Bureau

One generic office floor was established as the geometry model. Model dimension could be found in Figure 1. Window to wall ratio (WWR) of each exterior wall was 0.4. The height of the sill was 0.8m and the floor height was 3m. The distance between central points of the neighboring window is 4m. Daylight performance metrics were evaluated on the illuminance map with cell dimensions of 0.5*0.5m at a height of 0.8m.

Performance metrics used for comparison includes:

- DF (Daylight Factor): the ratio between the indoor illuminance and the outdoor illuminance on a horizontal surface that sees the entire sky without obstructions [10].

- Indoor daylight illuminance distribution on characteristic days as spring and autumnal equinox together with summer and winter solstices.
- DA (Daylight Autonomy): the percent of occupied time period when daylight levels on work plane exceed a specified target illuminance [11].
- UDI_{100}, $UDI_{100\text{-}2000}$, and UDI_{2000} (Useful Daylight Illuminance): the percent of occupied time period when work plane illuminance levels are useful for the occupant. Based on the conventional range of 100 and 2000lux, UDI has been categorized into three metrics: UDI_{100}, UDI $_{100\text{-}2000}$, and UDI_{2000}. These metrics correspond to the conditions when UDI is achieved (100-2000lux), exceeded (>200lux) and fell-short (<100lux) [10, 11].

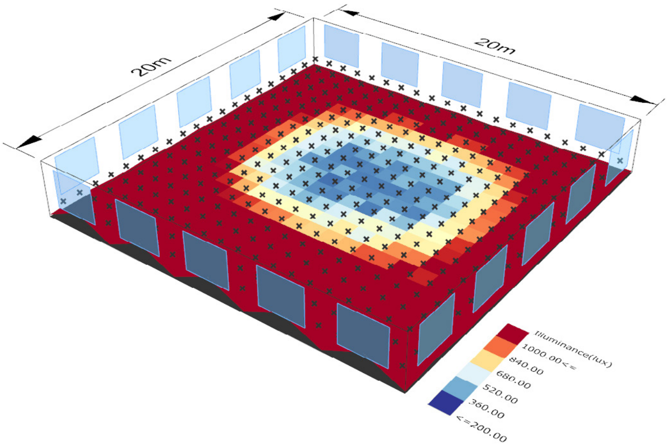

Figure. 1. The layout and dimension of the geometry model and illuminance map grid

3. Results

Figure 2 shows the DF results of Shanghai and Beijing as examples. The figure has been organized in three column. Each column represents the result from one certain kind of TMY data. Simulation result indicated that with the same geometry model, the variation between cases with different TMY data could be ignored.

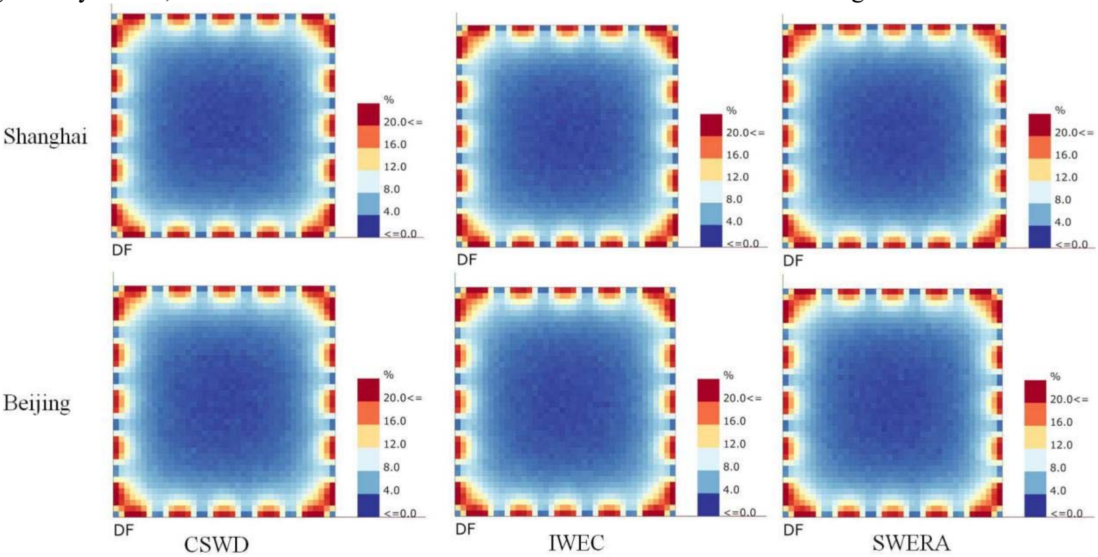

Figure. 2. Daylight Factor (DF) under different TMY data (Shanghai and Beijing)

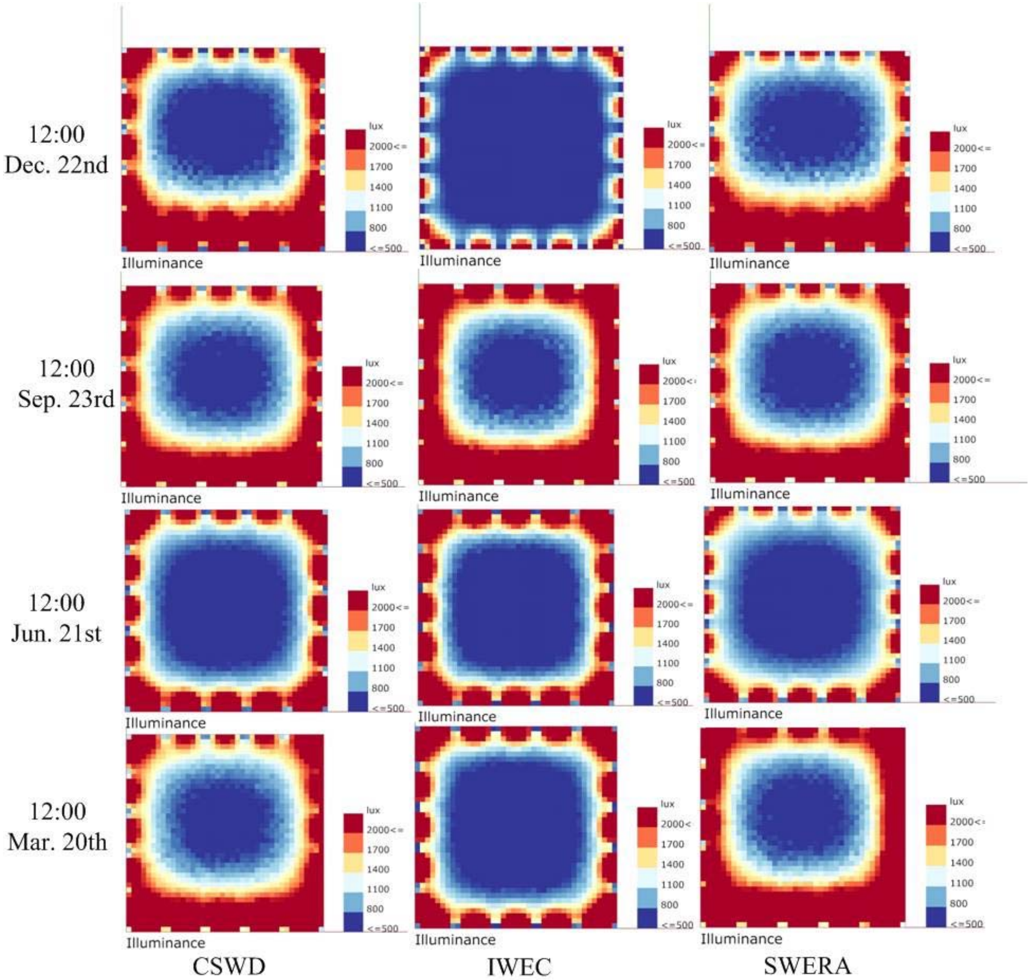

Figure. 3. Daylight illuminance distribution under different TMY data (Beijing)

Figure 3 takes Beijing as an example to present the distribution of indoor daylight illuminance at 12:00 on characteristic days. For all the four cities, remarkable variation could be observed with distribution of illuminance between using different TMY data. Comparing with other TMY data, IWEC data resulted a significant lower level of illuminance for all the four cities.

Figure 4 and figure 5 shows the distribution of DA along with the annual mean level on the whole floor. Obvious variation of distribution could also been found between each figure panel column. The variation caused by using different TMY data is 10% to 20% for each city. For Beijing, Shanghai and Kunming, annual mean levels of DA rank as DA_{SWERA}> DA_{IWEC}>DA_{CSWD}. For Harbin, the rank is DA_{CSWD}> DA_{SWERA}>DA_{IWEC}.

Figure 6 compares the UDI levels. As UDI 100-2000 suggests the percent of occupied time period when work plane illuminance level is achieved as useful for the occupant, $UDI_{100\text{-}2000}$ is the main concern among all three metrics. For Shanghai, the variation of $UDI_{100\text{-}2000}$ between different TMY data is less than 2%, which is relatively marginal. However, for Kunming, the variation is more than 10% and the available level of UDI is apparently lower when using CSWD as weather input file. For Beijing and Harbin, using CSWD would result the highest available level of UDI. This diverse pattern increases the difficulty of interpreting horizontal comparison between simulations conducted with different TMY data.

4. Discussion

From the result session, we can find out that Daylight Factor (DF) is not influenced by the selection of TMY data. However, for other performance metrics in this study, variation brought by TMY data selection is remarkable. This is mainly due to the difference between the underlying models of these metrics.

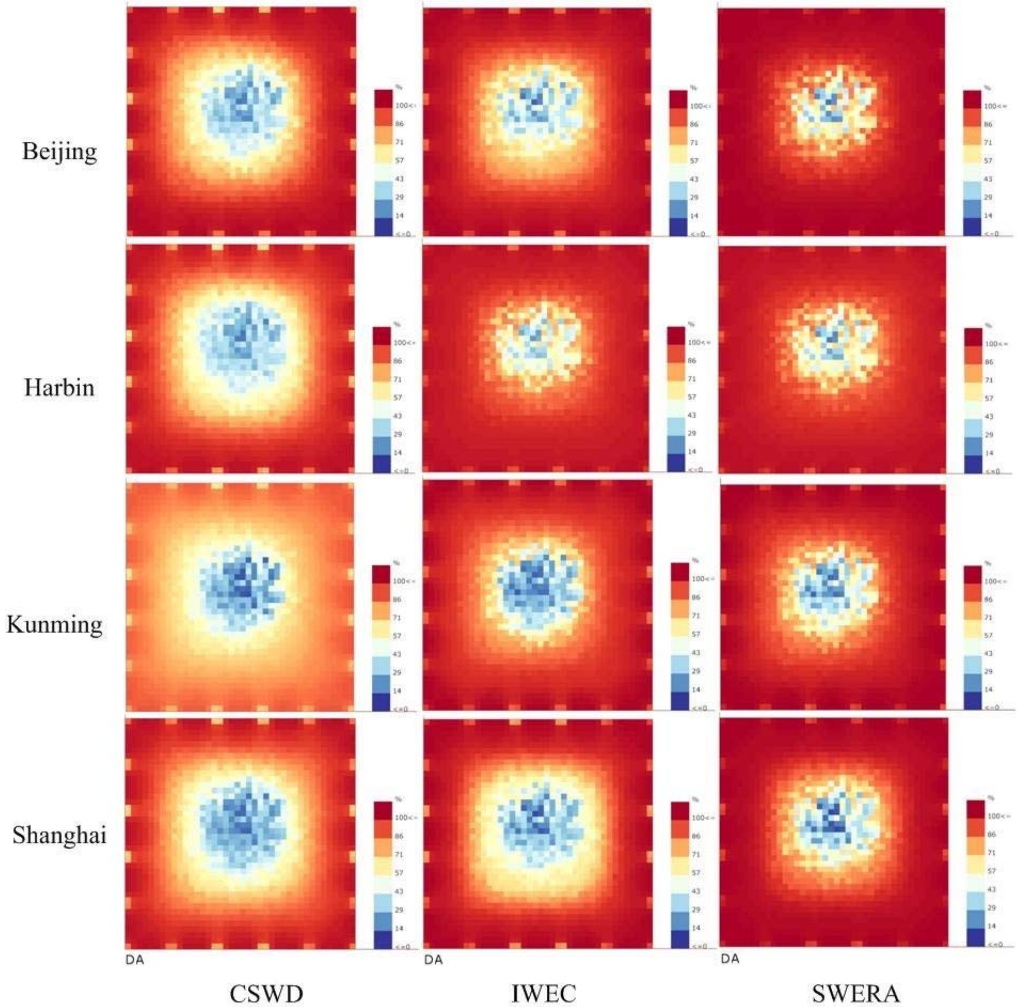

Figure. 4. The Daylight Autonomy (DA) with different TMY data in various cities

Rather than using climate-based daylight condition, DF calculation adopts CIE overcast sky. Direct sunlight is excluded and performance is evaluated conservatively under the worst case. As a static metric, DF is not sensitive to the real climate condition, not to mention the type of TMY data. Such treatment inevitably underestimates the energy efficiency potential of daylight utilization. As a result, although DF is once one of the most common indices for measuring the daylight availability, currently it is gradually replacing by metrics based on real climate conditions.

Considered as dynamic metric, DA, UDI and illuminance distribution take account realistic sky conditions as well as climate parameters such as illuminance values. Consequently they are relatively sensitive to the TMY type. One thing to be noted is that for now illuminance data are still not the conventional monitoring parameters of meteorological station. Most illuminance parameters used in daylight simulation are derived from recorded irradiance data with Perez's model [12]. However, this does not mean that including solar radiation items in weighting scheme is sufficient. The derivation of illuminance data involves more factors [12] and could not be represented by irradiance data only.

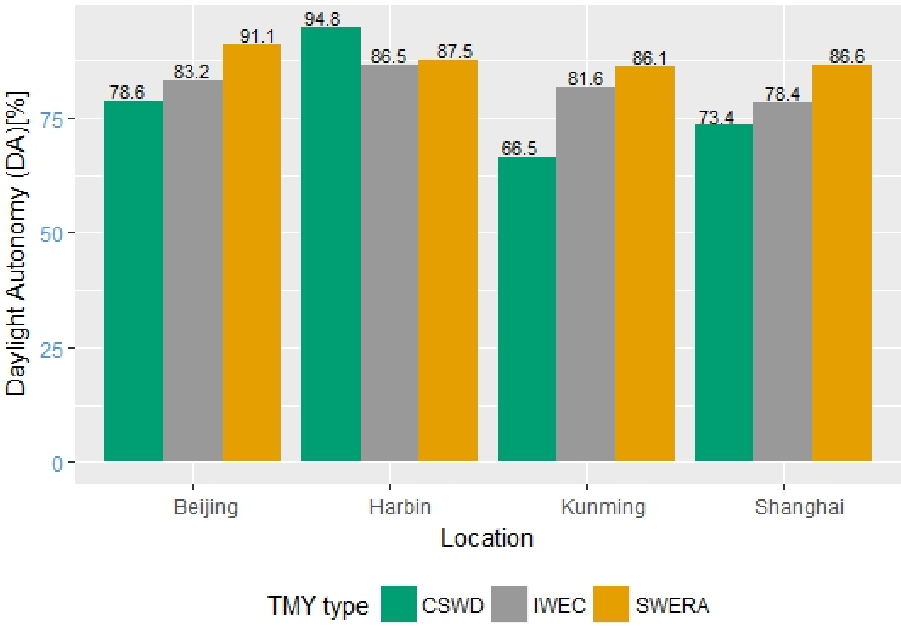

Figure 5.Annual mean level of Daylight Autonomy (DA) with different TMY data

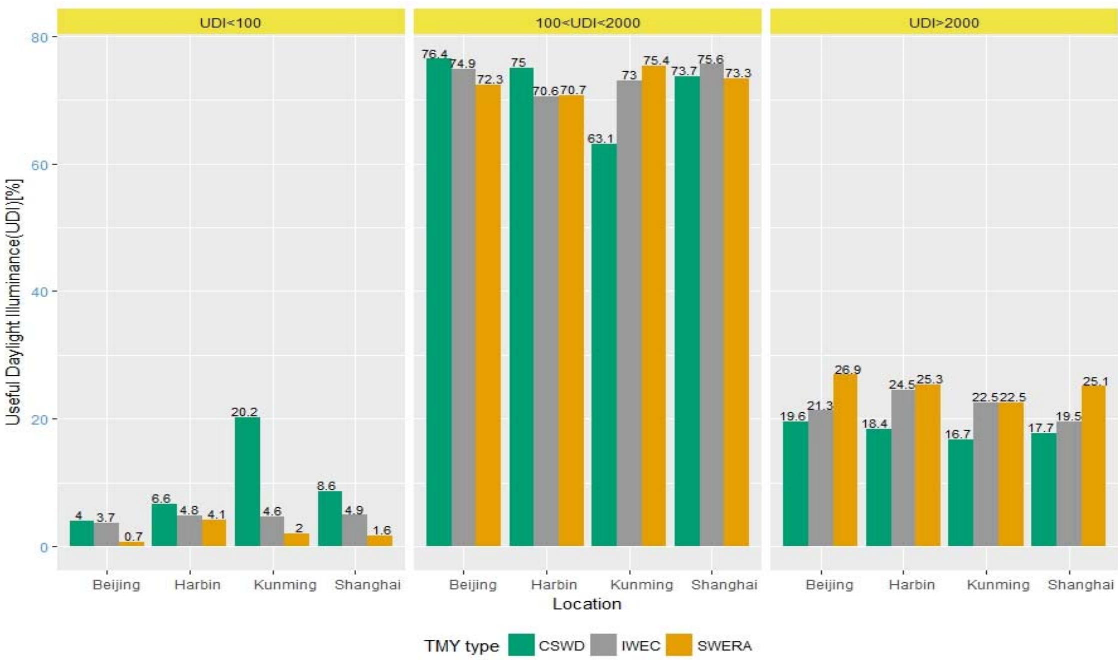

Figure. 6. The distribution of UDI with different TMY data in various cities

5. Conclusions

In this study, we conducted a case study to investigate whether using different existing TMY data of one specific location would result a divergence of conclusion in daylight-related simulations. Three TMY types from each of four cities in China were deployed. A generic office floor model with operation hours mainly during the daytime was accepted for its potential in daylight utilization.

The result indicates that static metric as DF is insensitive to TMY data type and the variation between using different TMY data could be ignored. DA, UDI and illuminance distribution, as dynamic metrics taking account realistic climate condition, are sensitive to TMY types. When comparing horizontally between different studies on daylight simulation, researchers should take caution of the potential influence brought by TMY selection.

As the first part of a series of studies, the result of this paper also implies an urgent need for developing the new TMY methodology for daylight utilization with concern of both light and thermal aspects.

References

[1] I.J. Hall, R.R. Prairie, H.E. Anderson, E.C. Boes, Generation of a typical meteorological year, in: Analysis for solar heating and cooling, San Diego, CA, USA, 27 Jun 1978, 1978.
[2] H. Lund, The Design Reference Year User's Manual, Thermal Insulation Laboratory, Technical University of Denmark, Report 274, 1995.
[3] R. Festa, C.F. Ratto, Proposal of numerical procedure to select reference years, Sol Energy, 50 (1993) 9-17.
[4] L.W. Crow, Weather year for energy calculations, ASHRAE J., 26 (1984) 42-47.
[5] A. de Miguel, J. Bilbao, Test reference year generation from meteorological and simulated solar radiation data, Sol Energy, 78 (2005) 695-703.
[6] M. Gazela, E. Mathioulakis, A new method for typical weather data selection to evaluate long-term performance of solar energy systems, Sol Energy, 70 (2001) 339-348.
[7] K. Skeiker, Comparison of methodologies for TMY generation using 10 years data for Damascus, Syria, Energ Convers Manage, 48 (2007) 2090-2102.
[8] S. Janjai, P. Deeyai, Comparison of methods for generating typical meteorological year using meteorological data from a tropical environment, Appl Energ, 86 (2009) 528-537.
[9] W. Marion, K. Urban, User's manual for TMY2's: Derived from the 1961-1990 National Solar Radiation Data Base, Nasa Sti/recon Technical Report N, 96 (1995).
[10] A. Nabil, J. Mardaljevic, Useful daylight illuminances: A replacement for daylight factors, Energy & Buildings, 38 (2006) 905-913.
[11] C.F. Reinhart, J. Mardaljevic, Z. Rogers, Dynamic daylight performance metrics for sustainable building design, Leukos, 3 (2006) 7-31.
[12] R. Perez, P. Ineichen, R. Seals, J. Michalsky, R. Stewart, Modeling daylight availability and irradiance components from direct and global irradiance, Sol Energy, 44 (1990) 271-289.