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Synthesis of Typical Meteorological Year (TMY) data for optimal design of air-conditioning systems in Burkina Faso

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ABSTRACT

The correct selection of a typical meteorological year is an important factor for the accurate design and optimization of air-conditioning equipment. In this study, a simplified method has been applied to prepare Typical Meteorological Year (TMY) datasets for three cities (Ouagadougou, Bobo-Dioulasso, and Dori) in Burkina Faso with the view of facilitating the optimal design of air-conditioning systems. The method consists, for each month, of calculating the absolute difference between the quartiles of each year and those of all the years of the study period, the latter being taken as the reference, and then selecting the year for which this difference is smallest. This year is then taken as the typical year for the month in question. The procedure is repeated for all the other months, and the months of the selected years are concatenated to form the TMY. The comparison of the monthly mean of the TMY data with that of the long-term (LT) data confirms that they are representative, and can replace validly the long-term data in air-conditioning systems design and optimization.

RESUME

La bonne sélection d'une année météorologique type est un facteur important pour la conception et l'optimisation des équipements de climatisation. Dans cette étude, une méthode simplifiée a été appliquée pour préparer des bases de données d'une année météorologique type (AMT) pour chacune des trois villes (Ouagadougou, Bobo-Dioulasso et Dori) du Burkina Faso en vue de faciliter la conception optimale des systèmes de climatisation. La méthode consiste, pour chaque mois, à calculer la différence absolue entre les quartiles de chaque année et ceux de l'ensemble de toutes les années de l'étude, ces derniers étant pris comme référence, puis à sélectionner l'année pour laquelle cette différence est la plus faible. Cette année est alors considérée comme l'année type pour le mois en question. La procédure est répétée pour tous les autres mois et les mois des années sélectionnées sont concaténés pour former l'AMT. La comparaison de la moyenne mensuelle des données de l'AMT avec celle des données à long terme (LT) confirme qu'ils sont représentatifs et peuvent remplacer valablement les données à long terme dans la conception et l'optimisation des systèmes de conditionnement d'air.

I. INTRODUCTION

An annual prediction of the cooling performance of an air-conditioning system using computer simulation usually requires hourly meteorological data covering the whole year. As meteorological parameters have inter-annual variations, hourly meteorological data from several years should be used to obtain the average performances of such systems. However, the use of such data is impractical and time-consuming. Weather data can vary significantly from one year to another, so creating a Typical Meteorological Year (TMY) data that can represent the long-term weather data sets is considered a very important input in modelling, designing and performance evaluation of evaporative cooling systems(Chiesa, 2016). A careful weather data analysis is essential for the successful selection and implementation of passive cooling techniques and proper sizing of cooling equipment in general (Chiesa, 2019). The most widely used weather data are the Test Reference Year (TRY) and the Typical Meteorological Year (TMY). In this study, TMY was developed and the dataset for this year was proposed to replace that of several years. This TMY constitutes a database for performance studies of evaporative cooling systems. To develop a typical weather year, it's important to consider a long period to take into account local climatic fluctuations. Our study period is twenty (20) years, from 2001 to 2020, and covers three cities, namely Ouagadougou, Bobo-Dioulasso, and Dori, each representing a climatic zone of Burkina Faso. Several methods have been developed to generate typical meteorological years. Of these, the one proposed by (Nik,

2017) is the most suitable for this study. TMY datasets of the three locations are synthesized based on selecting twelve typical meteorological months (TMM) and concatenating them to create a weather file for one year. Unlike the common method introduced by (Hall et al., 1978), in this study, only the wet bulb temperature is considered for simplifying purposes because this climate variable reflects the interactions of several climatic parameters mainly the rainfall, the dry bulb temperature and the relative humidity. The synthesized database provides designers, architects, engineers, and other users with an annual dataset consisting of hourly meteorological values that typify conditions at a specific location over a longer period. This dataset is based on more recent and accurate data, derived from the 2001-2020 NASA POWER update data, and has a greater geographical coverage, i.e. all three climatic zones in Burkina Faso.

II. SELECTED LOCATIONS

Burkina Faso climate context has been selected for this study. (Beck et al., 2018) developed a climate zone classification system that divides the country into three different climate zones. Each climate zone has a representative city. The Soudanian zone is represented by Bobo-Dioulasso, the Savannah zone by Ouagadougou, and the Sahelian zone by Dori. Their geographical locations are illustrated in Fig. 1. The selected locations represent the diverse range of climates in Burkina Faso.

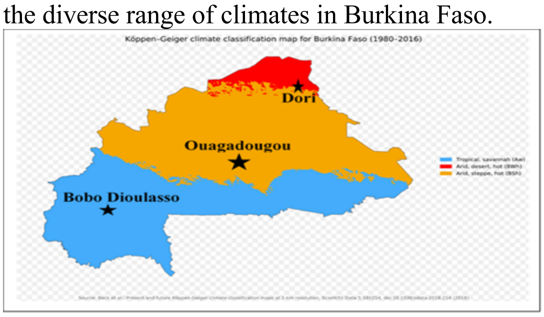

Fig. 1: Koppen-Geiger climate classification map for Burkina Faso (1980-2016)(Beck et al., 2018)

III. MATERIALS AND METHOD

The commonly used approach to prepare climate data is to subset the data into a typical meteorological year first introduced by (Hall et al., 1978) which involves a statistical analysis of the study period to select one typical meteorological month for each month of the year. This method has subsequently been used in the building energy performance field to reduce the number of simulations required to accurately describe the effects of a typical climate on the building (Aparicio-Ruiz et al., 2018; Bhamare et al., 2019; Di et al., 2010; Salmeron et al., 2012). This method has been further expanded on by (Nik, 2017) to synthesize typical and extreme datasets out of regional climate models or observational datasets. Due to the numerous uncertainties in climate modeling, there are many variables to consider for synthesizing a weather dataset. Consequently, to reduce the number of potential simulations required to synthesize a weather dataset, this method was developed to simplify these assessments. The method produces one typical weather dataset out of a long-term weather database only based on the air dry-bulb temperature, to decrease the amount of data without losing the details and quality of the original database. This method helps to minimize the number and duration of the required simulations in synthesizing weather datasets, while also keeping the quality of the data on a similar level to the original data.

In this study, a similar approach is adopted to create a Typical Meteorological Year (TMY) dataset, which represents the typical climate conditions in the considered location during the considered period, based on 20-years dataset from NASA POWER database. This TMY dataset consists of 12 typical meteorological months (January through December), with individual months selected from different years of the period of record. For example, in the 20 years' database, all 20 Januarys are examined, and the one judged most typical is selected to be included in the TMY. The other months of the year are treated in a like manner, and then the 12 selected typical months are concatenated to form a complete year. These monthly datasets contain actual time series of meteorological measurements provided by NASA. The TMY is created only based on the hourly values of the wet bulb temperature of ambient air. The hourly wet bulb temperature of the 20-years weather data is a 20×8760 matrix, which will be divided into 12 matrices corresponding to 12 months in a year.

For each month, wet bulb temperature distribution is found by calculating its quartiles for each year separately and for all the 20 years together, which the latter is considered as the reference. For each month, the year with the most similar distribution to the reference (i.e. the year which its quartiles have the least absolute difference from the quartiles of the reference during the considered month) will be selected as the year with the typical meteorological month. This is similar to comparing the cumulative distribution function (CDF) of the single and reference (or long-term) data sets and finding the one closest to the long-term distribution (which is referred as Finkelstein–Schafer (FS) statistics (Ousmane COULIBALY, 2011)). For this work, quartiles were calculated using "quantile" command in R and the cumulative probability interval between 0 and 1 was divided into 100 evenly spaced probabilities to get a finer and more accurate distribution. After repeating the procedure for all the months, twelve (12) years (among 20 years) which represent the typical year for each month are recognized.

IV. RESULTS AND DISCUSSIONS

IV.1. Results and discussions

A total of three (3) tables were generated for selecting the TMM. Table 1,Table 2Table 3 summarize the absolute difference between the quartiles of each year and that of all 20 years for Ouagadougou, Bobo-Dioulasso, and Dori respectively. All the tables show variation from one month to another. For each month, the least absolute difference (green highlight color) is selected and the correspondent year constitutes the typical year of that month.

Table 1: The absolute difference of quartiles obtained for Ouagadougou

	January	February	March	April	May	June	July	August	September	October	November	December
2001	2.4	4.36	2.68	0.77	0.32	0.41	0.14	0.12	0.28	2.12	2.82	0.94
2002	1.34	3.39	1.95	0.9	0.25	0.2	0.2	0.12	0.14	1	2.74	1.59
2003	1.45	0.43	2.01	1.38	0.82	0.32	0.15	0.07	0.26	0.77	1.56	0.59
2004	0.91	0.53	2.71	1.54	0.19	0.36	0.45	0.13	0.11	0.42	0.82	0.56
2005	1.37	2.97	2.77	1.12	0.26	0.11	0.08	0.2	0.26	0.98	1.72	0.74
2006	2.72	1.12	2.63	2.96	0.67	0.09	0.25	0.14	0.19	0.73	2.62	2.05
2007	1.72	2.79	2.22	2.1	0.31	0.16	0.17	0.21	0.2	0.54	1.04	0.23
2008	2.16	2.54	1.25	3.49	0.75	0.16	0.27	0.21	0.22	0.45	1.74	0.38
2009	0.51	3.38	2.18	1.38	0.33	0.04	0.1	0.08	0.15	0.82	0.22	0.49
2010	0.48	2.75	1.48	1.21	0.88	0.15	0.18	0.1	0.15	0.81	2.44	0.78
2011	1.79	2.58	4.47	1.38	0.34	0.1	0.14	0.06	0.1	0.61	0.69	2.38
2012	0.31	0.96	2.03	1.06	0.37	0.47	0.24	0.27	0.12	0.81	3.05	1.74
2013	1.34	0.86	5.17	1.89	0.36	0.09	0.22	0.25	0.15	0.93	0.93	0.24
2014	3.19	0.47	1.32	1.71	0.2	0.43	0.37	0.08	0.23	0.29	1.56	0.59
2015	1.97	0.6	0.75	5.39	0.24	0.53	0.57	0.22	0.48	1.34	0.57	1.58
2016	1.07	1.38	1.69	2.27	0.53	0.04	0.05	0.24	0.09	0.32	1.62	2.01
2017	1.21	0.86	0.9	0.34	0.61	0.18	0.27	0.34	0.37	1.55	1.8	0.6
2018	1.1	3.05	2.28	0.94	0.52	0.12	0.14	0.2	0.1	0.72	1.46	0.56
2019	0.66	1.31	0.48	0.65	0.45	0.2	0.06	0.1	0.53	0.94	1.33	0.2
2020	0.96	1.71	2.08	1.76	0.27	0.21	0.14	0.1	0.15	0.75	0.44	3.37

Table 2: The absolute difference of quartiles obtained for Bobo-Dioulasso

	January	February	March	April	May	June	July	August	September	October	November	December
2001	2.56	5.26	1.14	0.46	0.21	0.39	0.16	0.18	0.13	0.6	1.54	1.46
2002	1.23	3.69	0.65	0.42	**0.07**	0.12	0.21	0.15	0.18	0.35	1.81	2.54
2003	1.37	1.24	2.74	0.67	0.12	0.26	0.15	0.08	0.41	0.46	1.32	**0.33**
2004	1.64	0.88	1.57	**0.27**	0.12	0.28	0.42	0.15	0.13	0.19	**0.21**	2.37
2005	1	2.76	3.58	1.13	0.13	0.1	0.2	0.28	0.23	0.28	0.55	0.64
2006	1.9	0.92	1.61	0.82	0.27	0.11	0.16	0.29	0.14	0.45	2.2	2.07
2007	1.47	2.93	2.1	1	0.36	0.13	0.15	0.25	0.18	0.27	0.77	0.59
2008	2.81	2.23	0.84	2.68	0.3	0.11	0.25	0.24	0.1	0.2	1.47	0.93
2009	0.51	4.22	2.51	0.82	0.26	0.06	0.09	0.17	0.08	0.36	0.65	0.71
2010	0.6	3.49	0.89	0.98	0.49	0.09	0.11	0.08	0.24	0.32	1.2	1.18
2011	2.47	2.3	4.22	1.11	0.17	0.18	0.1	0.15	**0.06**	0.14	0.34	2.91
2012	0.8	**0.41**	1.99	0.61	0.39	0.44	0.38	0.27	0.29	0.24	1.93	0.88
2013	**0.4**	0.53	4.06	0.68	0.19	0.12	0.19	0.21	0.09	0.41	0.33	0.94
2014	2.4	0.93	2.22	0.97	0.17	0.4	0.39	**0.07**	0.1	**0.13**	1.69	0.61
2015	1.26	1.72	1.91	1.75	0.08	**0**	0.47	0.19	0.39	0.73	0.63	1.17
2016	1.12	2.18	0.61	0.93	0.34	0.12	**0.07**	0.19	0.08	0.32	1.02	1.55
2017	1.13	0.8	**0.17**	0.77	0.31	0.08	0.27	0.15	0.35	0.75	0.96	0.35
2018	1.44	3.19	1.85	0.35	0.15	0.07	0.12	0.38	0.15	0.36	1.19	0.82
2019	1.08	0.75	1.18	0.58	0.14	0.38	0.09	0.07	0.39	0.38	0.93	1.28
2020	1.91	1.49	1.3	0.85	0.28	0.22	0.12	0.08	0.07	0.7	0.99	2.99

Table 3: The absolute difference of quartiles obtained for Dori

	January	February	March	April	May	June	July	August	September	October	November	December
2001	2.44	3.9	3.08	1.89	0.63	0.32	0.16	0.17	0.2	3.02	3.16	0.88
2002	1.16	3.17	1.35	1.07	0.47	0.3	0.26	0.16	0.15	1.59	2.33	0.49
2003	0.75	0.74	1.51	1.1	2.02	0.31	0.12	0.07	0.35	0.84	0.78	1.18
2004	2.87	1.82	0.61	4.55	0.87	0.8	0.91	0.29	0.41	0.76	1.44	2.42
2005	0.91	4.34	3.12	1.44	0.49	0.17	0.09	0.15	0.19	1.38	2.31	0.84
2006	2.93	0.8	2.81	3.69	2.32	0.26	0.34	0.19	0.13	0.88	2.84	1.95
2007	1.63	2.25	1.68	1.36	0.44	0.15	0.15	0.22	0.25	0.98	0.61	0.26

2008	1.88	2.54	1.37	3.04	1.05	0.23	0.27	0.23	0.07	0.5	2.16	0.32
2009	0.34	3.01	1.17	1.16	0.28	0.34	0.2	0.18	0.05	1.4	0.35	0.55
2010	1.04	1.63	1.76	1.31	1.78	0.43	0.16	0.14	0.17	1.24	2.43	1.6
2011	0.7	1.69	1.91	1.48	0.6	0.36	0.16	0.04	0.12	0.51	2.06	3.16
2012	0.22	0.97	2.21	1.5	0.85	0.32	0.21	0.21	0.11	0.71	3.67	1.03
2013	0.21	1.2	3.28	2.44	1.32	0.3	0.13	0.13	0.1	1.4	0.89	0.58
2014	2.89	0.94	2.11	0.64	1.01	0.6	0.45	0.11	0.08	0.8	0.4	0.74
2015	2.52	0.35	0.54	6.88	1.52	0	0.55	0.27	0.37	1.72	0.72	2.38
2016	2.36	1.17	4.33	5.29	1.36	0.45	0.45	0.14	0.27	0.79	3.8	4.11
2017	3.17	1.89	1.93	2.9	1.44	0.29	0.24	0.06	0.09	1.06	0.84	2.67
2018	1.78	2.53	0.54	2.69	1.81	0.33	0.09	0.16	0.16	0.93	0.66	0.98
2019	1.38	2.89	0.45	1.03	1.13	0.3	0.23	0.15	0.64	1.38	1.28	1.44
2020	0.57	1.68	1.56	2.45	1.29	0.45	0.29	0.19	0.11	0.56	0.79	3.47

In Table 4, there are the twelve (12) selected TMM for each location from January to December. The results show that all the 12 TMM spread across the whole 20 years period for each location. Also, it is found that for Ouagadougou, 2016 gives more TMM (June, July, and September); for Bobo-Dioulasso, 2004 and 2014 give more TMM; for Dori 2009 gives more TMM (May, September, and November).

Table 4: The Typical Meteorological Year for each location

Ouagadougou											
January	February	March	April	May	June	July	August	September	October	November	December
2012	2003	2019	2017	2004	2016	2016	2011	2016	2014	2009	2019
Bobo-Dioulasso											
January	February	March	April	May	June	July	August	September	October	November	December
2013	2012	2017	2004	2002	2015	2016	2014	2011	2014	2004	2003
Dori											
January	February	March	April	May	June	July	August	September	October	November	December
2013	2015	2019	2014	2009	2015	2018	2011	2009	2008	2009	2007

To verify the validity of the generated TMY data for each city, a comparison was made with the long-term (LT) average monthly means for dry bulb (a) and wet bulb (b) temperatures. Observations from Fig. 2 through Fig. 4 indicate a strong correlation between the LT and the generated TMY monthly means values. Specifically, Fig. 2 a&b highlight similarities between the TMY and LT mean for Ouagadougou, except for February, where a notable discrepancy exists for dry bulb temperature. Similarly for Bobo-Dioulasso, Fig. 3 a&b reveal consistent trends, albeit with differences observed in May and November for dry bulb temperature. Lastly, Fig. 4 a&b demonstrate a favorable match between the long-term (LT) and the TMY monthly means for Dori, affirming the accuracy of predictions for this city. To further evaluate the TMY's representativeness, comparisons were made against the 2021-year monthly means data. Despite slight overestimations, the overall proximity of the three curves suggests a high degree of similarity.

However, it's important to note that while the TMY closely aligns with the LT average for wet bulb temperature, discrepancies arise for dry bulb temperature. Probably, this is explained by the fact that the selection process for the meteorological year relies on a single meteorological index (the wet-bulb temperature), which limits the representation of the importance of the other weather parameters such as the dry-bulb temperature in the final meteorological year. (Nik, 2017) made the same observation when he used to generate typical and extreme weather data sets for hygrothermal simulation of the building's components.

Fig. 2: Generated TMY, LT, and 2021 monthly mean of DBT (a) and WBT (b) at Ouagadougou.

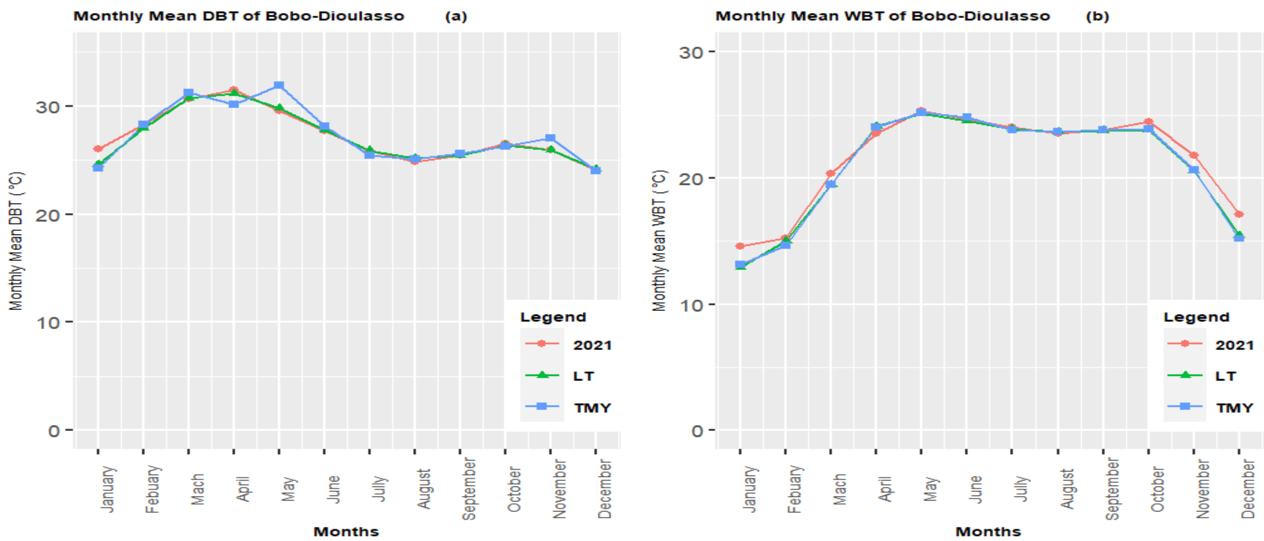

Fig. 3: Generated TMY, LT, and 2021 monthly mean of DBT (a) and WBT(b) at Bobo-Dioulasso.

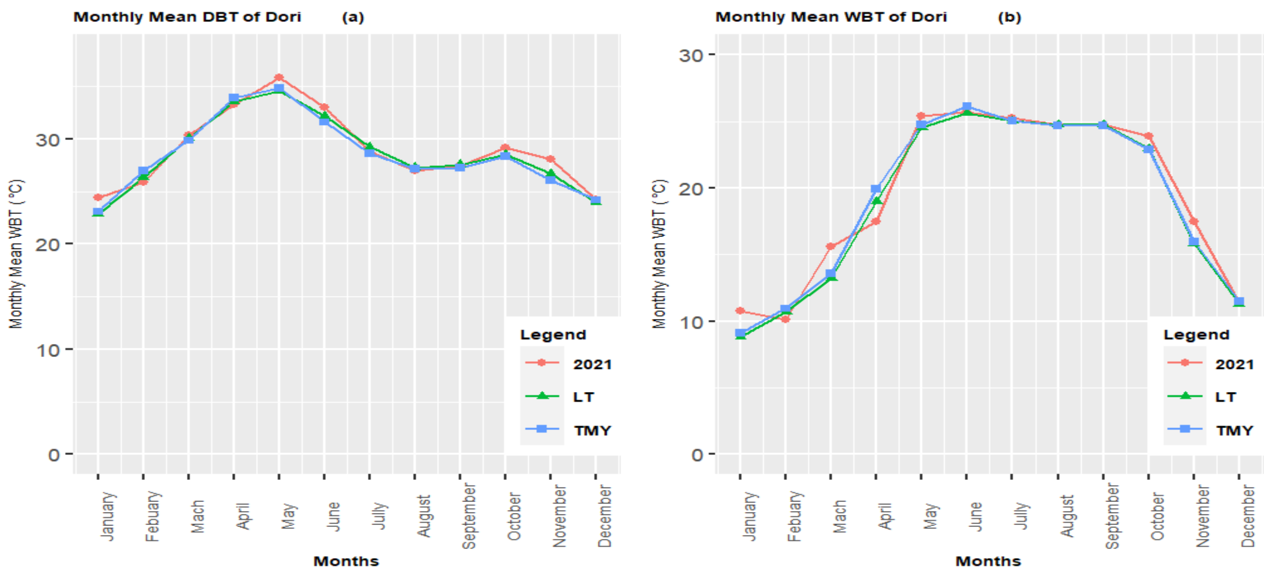

Fig. 4: Generated TMY, LT, and 2021 monthly mean of DBT (a) and WBT(b) at Dori.

Estimated Bias Error and Root Mean Square Errors of the dry and wet bulb temperatures are presented in Table 5. Negative values indicate underestimation, and positive values overestimation. Nevertheless, the RMSE and Biases values for all the cities considered in this study are relatively close to zero. This indicates that the TMY generated can validly represent the long-term meteorological weather conditions of the three cities, and thereby can be used to accurately simulate the performance of the air-conditioning systems.

Table 5: Estimated bias errors and root mean square errors in the monthly mean of dry and wet bulb temperatures

Cities	Performance index	Dry bulb temperature (ºC)	Wet bulb temperature (ºC)
Ouagadougou	Bias	-0.056	0.017
	RMSE	0.709	0.187
Bobo-Dioulasso	Bias	0.193	-0.006
	RMSE	0.794	0.172
Dori	Bias	-0.080	0.235
	RMSE	0.412	0.367

V. CONCLUSION

This study determined typical meteorological years for the three climatic zones of Burkina Faso. These three (03) typical years were determined using the method of the least absolute difference between the quartiles of each month of each year and the quartiles of the same month of the 20 years which is considered as reference. In this way, the data for typical years obtained from this method, which uses only the wet bulb temperature, can be proposed as baseline data for assessing the cooling potential of evaporative systems in the three climatic zones of Burkina Faso. This will provide a unique basis for the design of new evaporative cooling systems, for the simulation of the performance of existing evaporative systems, and for studies of any air-conditioning system requiring the use of climatic data.

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