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ANALYSIS OF THERMAL LOAD PATTERNS FOR COMMERCIAL BUILDINGS UNDER VARIOUS CLIMATE ZONES IN CHINA BASED ON CLUSTERING METHOD

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ABSTRACT

Traditional climatic zoning method divides China into 5 building thermal design zones by taking average temperatures of the coldest and hottest months, as well as accumulated temperature days in a year as the key indices. The method may not properly reflect the real building thermal characteristics. This paper therefore proposes a novel building thermal design zoning method based on the clustering of building indoor thermal performances of a typical commercial building model under different climates across China. K-Means method is adopted for clustering process. Three representative cities are selected to analyses the dynamic characteristics of thermal loads. Meanwhile, a new building thermal design zoning map is eventually developed, and thermal load patterns of the selected cities are also identified.

Keywords: climatic zoning, thermal load patterns, thermal performance, K-Means clustering, commercial building

1. INTRODUCTION

Climate zoning plays an important role in the achievement of energy conservation and carbon emission reduction by presenting adaptive energy-saving strategies during both design and operation of buildings.

China Academy of Building Research developed the national standard GB50176-2016: Thermal Design Code for Civil Building for HVAC design and operation of buildings [1]. Five building thermal design zones are divided according to climate differences [2]. However, instead of using the indoor thermal load performances of buildings as indices, the zoning method classified thermal zones based on the average temperatures of the coldest and hottest months and the accumulated temperature days in a typical meteorological year [1]. Internal relations between the outdoor climate and indoor thermal performance are hardly considered in detail. The zoning results may not be well matching the real building thermal loads.

As a consequence, the objective of this study is to present a novel climate-responsive strategy for climate zoning by adopting clustering methods and analyse the thermal load patterns of the buildings under the newly developed climate zones.

Building thermal performance data from 274 Chinese cities were obtained as the zoning indices. After comparing different clustering techniques [3-5], K-Means method was employed to identify the optimal cluster number. New building thermal design zones were finally developed and thermal load patterns were also identified in three representative cities. It is anticipated that the this study could assist architects and policy makers to better understand the influence of climates on building thermal performances and be used as a reference guideline for commercial building design in China.

2. METHODOLOGY

A flow chart of the developed strategy in this study is presented in 错误!未找到引用源。. It mainly consists of three parts: data preparation, clustering, and data interpretation.

Firstly, a typical building model is employed at the data preparation stage. TMY (i.e. Typical Meteorological Yea) data from 274 cities across China were utilised to generate the corresponding thermal load data. The generated thermal load data can be separated into two groups (i.e., annual data and hourly data).

Secondly, two groups of the thermal load data were processed by inter and intra city clustering, respectively. Hopkins statistic was employed to evaluate the clustering feasibility. K-means method was employed to generate clusters by prior comparison. The cluster quality was evaluated by Silhouette coefficient and Calinski-Harabaz index respectively. The optimal clusters corresponding to the optimal cluster number were then determined after the evaluation.

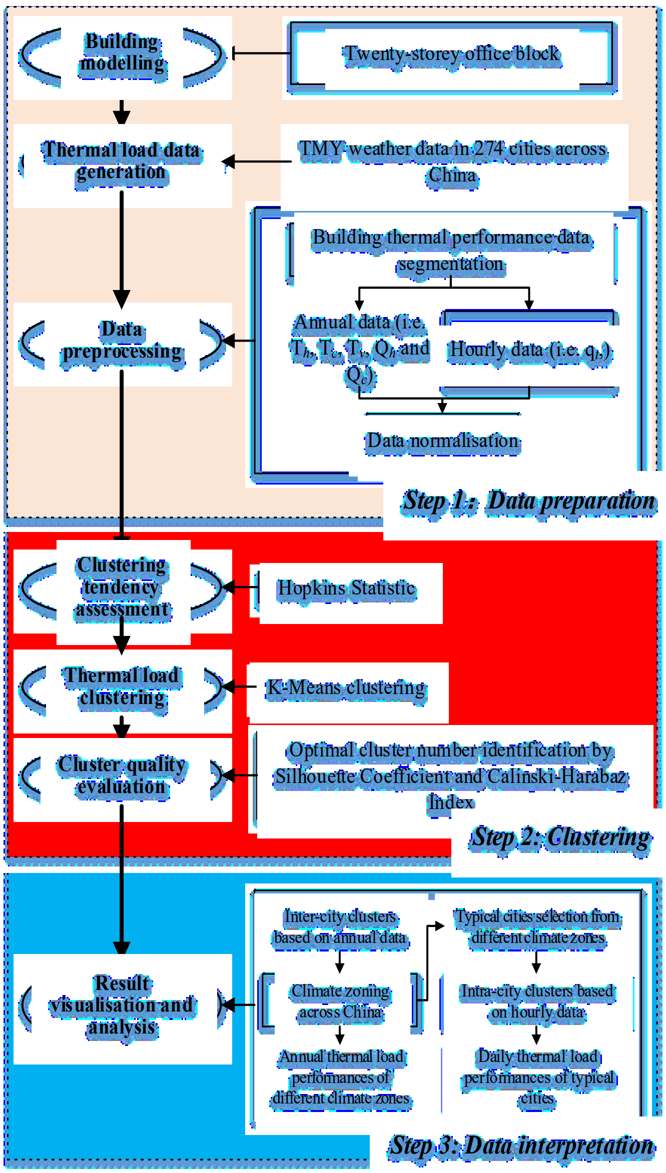

Fig 1 Schematic of research plan

Finally, the inter-city clusters were used for building thermal design zoning and annual thermal load performance analyses in each zone. Intra-city clusters from representative cities in different zones were selected for daily thermal load performances analyses.

3. RESULTS AND DISCUSSION

3.1 Inter-city clustering assessment

The Hopkins Statistic value was derived from randomly selected objects in the annual database to evaluate the inter-city clustering tendency. To avoid the random results, the Hopkins Statistic value was calculated for 100 times. The average Hopkins statistic value was found to be 0.6025, showing an inter-city clustering tendency.

The clustering results were assessed through average Silhouette Coefficient (SC) and Calinski-Harabaz Index (CHI) to identify the optimal cluster number. Considering too many building thermal zones may not be helpful for building thermal arrangements. For instance, China was divided into 5 main building thermal design zones by the traditional method [2]. Therefore, Fig only presents the performance of two indices when the cluster number rises from 3 to 8.

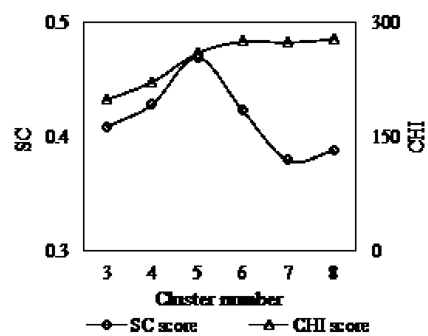

Fig 2 Inter-city clustering quality evaluation based on the method of K-Means

Fig shows the variations of SC and CHI scores when increasing the cluster number. An inverted v-shaped distribution of the SC score could be observed, and the highest SC score was found to be 0.473 when the cluster number was 5. CHI score increases when the cluster number increases, but the increase trend is slow down when the cluster number was more than 5, indicating the improvement of cluster number cannot significantly increase the clustering quality then. By considering both SC and CHI performances, the best cluster number was finally selected as 5.

3.2 Inter-city clustering results

The inter-city clustering results is presented in Table .

Table 1 Inter-city clustering results

Cluster No.	Average values of thermal load indices in each cluster					City amount in each cluster
	T_h	T_c	T_v	Q_h	Q_c	
1	1850	1785	1475	30	26	71
2	1266	2215	1628	19	28	136
3	1640	1716	1753	23	23	25
4	692	2970	1448	13	34	39
5	1	4757	353	2	52	3

By comparing the average values of thermal load indices of all the clusters presented in the table, some results could be summarized as following:

Heating hours: Cluster 1 > Cluster 3 > Cluster 2≫ Cluster 4 ≫ Cluster 5

Cities in Cluster 1, 2 and 3 have long heating periods; cities in Cluster 4 have relatively short heating periods; and cities in Cluster 5 nearly have no heating demands due to their tropical climates according to Köppen-Geiger climate classification [6].

Cooling hours: Cluster 5 ≫ Cluster 4 > Cluster 2 > Cluster 1 ≈ Cluster 3

Cities in Cluster 5 have the longest cooling periods; cities in Cluster 2 and 4 have relatively shorter cooling periods; and the cooling hours for cities from Cluster 1 and 3 are the least but still considerable even they are mostly located in frigid or plateau climate areas.

Ventilation hours: Cluster 3 > Cluster 2 > Cluster 1 ≈ Cluster 4 ≫ Cluster 5

Cities from cluster 1, 2, 3 and 4 have similar and considerable ventilation hours; cities in cluster 5 have the least ventilation hours.

Heating load: Cluster 1 > Cluster 3 > Cluster 2> Cluster 4 ≫Cluster 5

The ranking of heating loads is corresponding to that of heating hours. Cities in Cluster 1 have the maximum heating loads among all the cities; while the heating loads in cities from cluster 5 can be even ignored.

Cooling load: Cluster 5 > Cluster 4 > Cluster 2 > Cluster 1 > Cluster 3

Cities in Cluster 5 have the maximum cooling loads and cities from Cluster 3 have the least but still considerable cooling loads.

Based on inter-city clusters, the building thermal design zones obtained by using Kriging method in the ArcMap program [7] were proposed and the results are presented in Fig. Compared to previous China building thermal design zoning map in Ref. [1], the severe cold zone was generally divided into Cluster 1 and Cluster 3 zones. The cold zone and the hot summer, cold winter zone were grouped as Cluster 2 zone. The temperate zone and hot summer, warm winter zone were joined together as Cluster 3 zone. Besides, Hainan Island in the south of China was separated from the hot summer, warm winter zone and identified as an independent zone, i.e. Cluster 5.

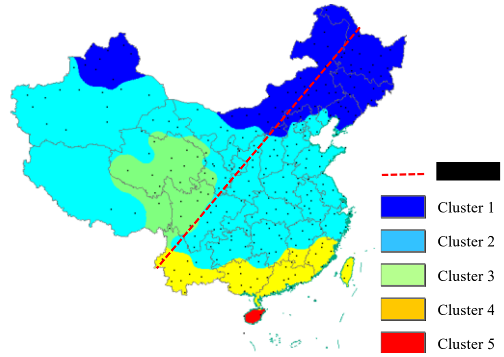

Fig 3 Building thermal design zoning based on inter-city clustering

3.3 Intra-city clustering assessment

According to Ref. [8], China can be divided by Hu Huanyong line and east part accounts for 94 % of the country's population [9]; Hainan Island associated with Cluster 5 only takes a small part of China. As a consequence, only three cities, i.e. Abagaqi, Zhengzhou and Baise which are closest to their cluster centers, were chosen as the representative cities in Cluster 1, 2 and 4 from east China for intra-city clustering analysis.

The process of intra-city clustering assessment was the same as the inter-city clustering assessment. The average Hopkins statistic values for the representative cities were 0.5679, 0.5732 and 0.6013 respectively, indicating the feasibility of intra-city clustering.

Comparison of the average of SC and the average of CHI for the intra-city clustering is presented in Table .

Table 2 Comparison of SC and CHI

	Average SC		Average CHI	
	Optimal cluster No.	Score	Optimal cluster No.	Score
Abagaqi	2	0.607	4	1517
	2	0.550	4	1471
Zhengzhou	2	0.570	4	1067
	2	0.505	4	898
Baise	2	0.573	2	833
	2	0.559	2	743

According to Table ,the appropriate cluster number for Baise can be identified as 2 by considering both SC and CHI. It is worth noticing that the optimal cluster number depends on the optimisation algorithm and evaluation method [10]. The optimal cluster number for Abagaqi and Zhengzhou therefore varies based on the clustering assessment algorithm selected (i.e., SC or CHI). This study only discuss the clustering results when the cluster number for both Abagaqi and Zhengzhou was selected as 4. Analysis of the other cluster number can be conducted by adopting same method.

3.4 Intra-city clustering results

Based on the optimal clustering results, the average building thermal loads of each cluster in the representative cities during worktime (07:00 to 20:00) are presented in Fig 4. Positive thermal loads indicate heating demands while negative thermal loads indicate cooling demands of the buildings.

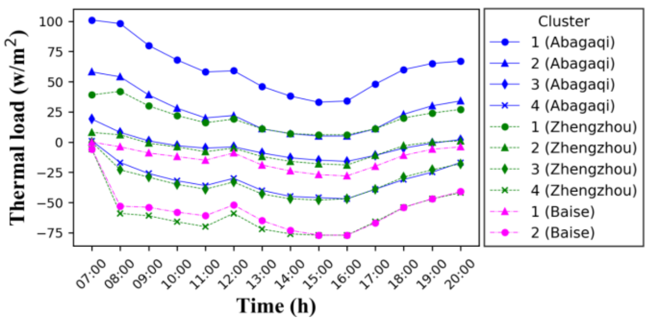

Fig 4 Time sequence based average thermal loads for each cluster in 274 cities

According to Fig 4, only Abagaqi and Zhengzhou have heating demands while all the cities have cooling demands. Fig 4 also shows that some clusters/curves are highly overlapped. Therefore, the clusters/curves regardless which cities they belong to, can be labelled with 5 thermal load patterns:

<u>Pattern 1</u>: High heating load (Cluster 1 of Abagaqi)
<u>Pattern 2</u>: Medium heating load (Cluster 2 of Abagaqi and Cluster 1 of Zhengzhou)
<u>Pattern 3</u>: Near zero thermal load (Abagaqi, Cluster 2 of Zhengzhou and Cluster 1 of Baise)
<u>Pattern 4</u>: Medium cooling load (Cluster 4 of Abagaqi and Cluster 3 of Zhengzhou)
<u>Pattern 5</u>: High cooling load (Cluster 4 of Zhengzhou and Cluster 2 of Baise)

4. CONCLUSIONS

A novel regionalized building design thermal zoning map was firstly developed by clustering indoor thermal performance indices including cooling hours, heating hours, mechanical ventilation hours, annual mean heating load and cooling load. Moreover, thermal load pattern distribution over the whole year was summarised through intra-city cluster labelling for three representative Chinese cities. Conclusions can be drawn as followed:

- Inter-city clustering results suggested the optimal thermal zone number to be 5, which is the same as the traditional zoning method. However, the geographical distribution of the new classified zones were different from the traditional ones.
- Intra-city clustering results from three representative cities indicated that, the optimal daily thermal load patterns could be identified as 2 or 4 for Abagaqi and Zhengzhou, and 2 for Baise.
- All the intra-city clusters could be labelled with 5 thermal load patterns accordingly (when the optimal daily thermal load patterns was selected as 4 for Abagaqi and Zhengzhou): high heating load, medium heating load, near zero thermal load, medium cooling load and high cooling load.

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