

Climate Zones for Underground Engineering in Different Areas in China

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Abstract. Thermal analysis has been made to find the regional factors affecting the thermal environment of underground engineering. The ground temperature (T_g), ventilating sensible heat ratio (VSHR) of fresh air of 208 major cities in different areas are calculated, and four climate zones including Cold, Dry, Humid, Hot-Humid zones are established for underground engineering. Based on the climate zones map, the energy conservation designs and analysis could be conducted specifically in different areas.

1. Introduction

An important feature of underground spaces is the higher protection against climatic influences by soil surrounding and a pleasant thermal comfort can be ensured with less energy [1]. Many spaces are built underground in China, including subway, parking lots, shopping malls, exhibition halls and service facilities [2,3]. The constant soil temperature in underground spaces could make the heating and cooling thermal loads be remarkably lower and a pleasant thermal comfort can be ensured [4]. Considering the complex underground thermal environment, Agus P. Sasmito et.al (2015) [5] developed the 3-D underground tunnel model, it showed that the virgin rock temperature had a great relation with the thermal environment. Maidment G et.al [6] studied the thermal conditions in underground railway environments in the UK. In China, according to the national standard Thermal Design Code for Civil Building (GB50176-93) [7], five climate zones are defined as Severe Cold (SC), Cold (C), Hot Summer & Cold Winter (HSCW), Hot Summer & Warm Winter (HSWW), and Mild (M) zones for aboveground buildings in different areas. Recently, based on field and laboratory studies from different climate zones in China, the Chinese evaluation standard for the indoor thermal environment was proposed [8]. Some studies also showed that the thermal comfort was different under different climate zones [9,10]. However, there is lack of the reasonable climate zones for underground engineering in China. With this purpose, the design of underground thermal environment calls for the reasonable thermal climate zones.

In this paper, major regional factors influencing on the heat transfer characteristics of the underground engineering are analyzed and the thermal climate zonal maps for underground engineering are estimated by selecting the reasonable indices.



2. Thermal environment in underground engineering in different areas

2.1. Heat transfer of surrounding rock-soil

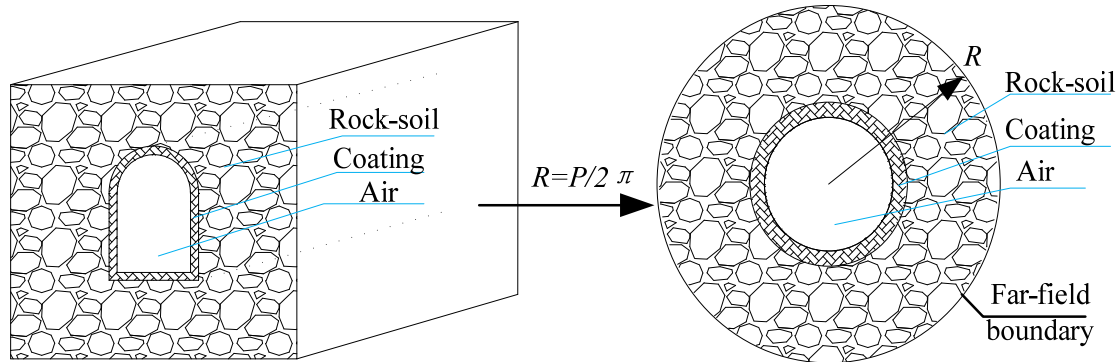


Figure 1. Simplification of the arched section to the circular section

The heat transfer of surrounding rock-soil can be simplified by using an equivalent cylinder shown in Fig.1. The heat transfer through the soil could be described by one dimension partial differential equation of the heat conduction **Eq. (1)** [11,12].

$$\left. \begin{aligned} \frac{\partial T(r,t)}{\partial t} &= a \left[\frac{\partial^2 T(r,t)}{\partial r^2} + \frac{1}{r} \frac{\partial T(r,t)}{\partial r} \right] & r_0 < r < +\infty, t > 0 \\ -\lambda \frac{\partial T(r,t)}{\partial r} \Big|_{r_0} &= h[T_a - T(r_0,t)] & t > 0 \\ T(r,t) &= T_g & r = +\infty, t > 0 \\ T(r,t) &= T_g & r_0 < r < +\infty, t = 0 \end{aligned} \right\} \quad (1)$$

Where T_g is annual mean ground temperature ($^{\circ}\text{C}$), T_a is air temperature in underground engineering ($^{\circ}\text{C}$). Because of the high density and quantity thermal medium of the surrounding soil, which can be treated as a heat reservoir. When $T_a > T_g$, i.e. the interior air temperature is lower than the T_g , a cooling effect takes place of the wall.

A typical underground engineering with 100 m×9 m×7 m (length×width×height) is chosen as a basic model. The thermo-physical properties of the surrounding rock-soil are shown in Table 1.

Table 1. Thermo-physical properties of the surrounding rock-soil in underground engineering

rock-soil thermal conductivity	rock-soil thermal diffusion coefficient	heat transfer coefficient
W/(m.K)	m ² /h	W/(m ² .K)
λ	a	h
2.57	0.0031	8.14

China has very broad geographical area and T_g is different in the different regions [13]. Based on the basic model of the underground engineering and the thermal environment meteorological parameters for China. According to Eq. (1), the heat flux through the wall of surrounding rock-soil Δq in typical cities are obtained as shown in Fig.2.

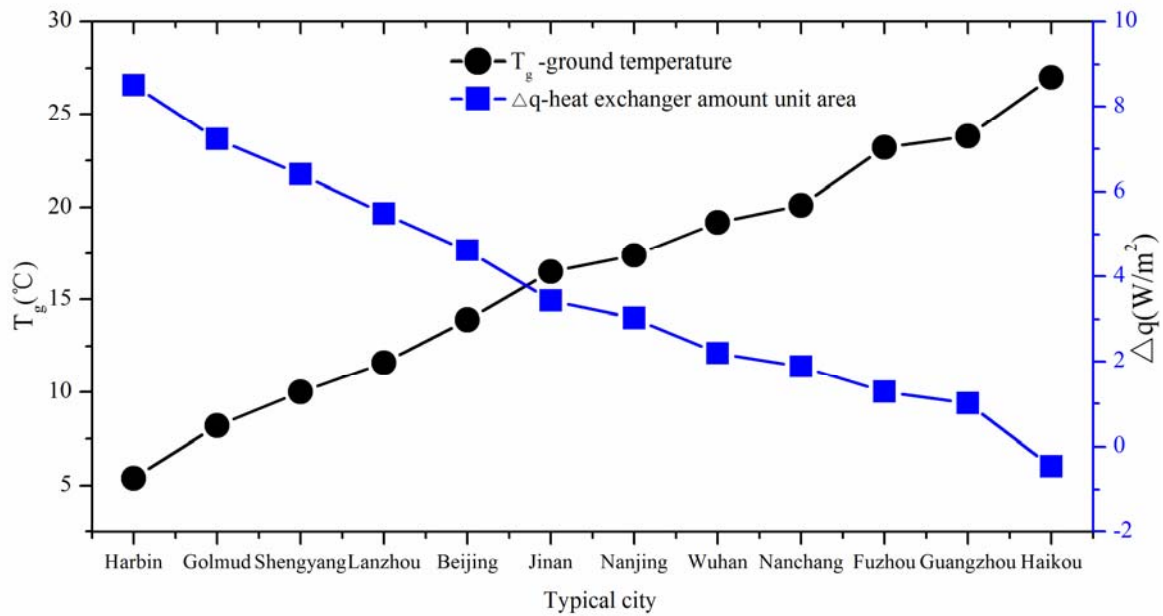


Figure 2. Δq of the surrounding rock-soil in typical cities with different T_g

In Fig.2, the different T_g causes different Δq in different regions. When the T_a is assumed as 26 °C, the Δq value is 4.8 W/m² in Beijing corresponding to T_g of 13.4 °C, while the Δq is obtained as 8.7 W/m² in Harbin with T_g of 5.4 °C. The Δq of the surrounding rock-soil in Haikou is obtained as -0.76 W/m². The negative values could be due to high T_g in these areas, it means that the surrounding rock-soil with higher T_g transfers heat to the interior air. The heat flux through the wall of surrounding rock-soil decreases with T_g , which has an important effect on the thermal characteristics in the underground engineering in different areas. Therefore, T_g should be used as the main index for climate zones.

2.2. Regional differences of the fresh air thermal loading

In order to analyze how the fresh air parameters influence the thermal characteristics of underground engineering, the cooling degree hours (CDH) of fresh air, cooling wetness hour (CWH) of fresh air and ventilating sensible heat ratio (VSHR) of fresh air are introduced to evaluate thermal characteristics of fresh air in different regions.

CDH_i is the difference of the air dry-bulb temperature between inside and outside of the engineering at i -th hour. CDH of one day is defined as the sum of CDH_i with higher outside air dry-bulb temperature than inside. It could be calculated by the Eq. (2).

CWH_i is the difference of the air moisture between inside and outside of the engineering at i -th hour. CWH of one day is defined as the sum of CWH_i with higher outside air moisture than inside. It is calculated as the Eq. (3).

$VSHR$: the ratio of sensible heat to total heat in fresh air loads. It is calculated as the Eq. (4), Eq. (5) and Eq. (6).

$$CWH_i = \begin{cases} d_i - d_a & (d_i > d_a) \\ 0 & (d_i \leq d_a) \end{cases} \quad (3)$$

$$VSHR = q_i / (q_i + q_r) \quad (4)$$

$$q_r = 0.001r_q \sum_{i=1}^n CWH_i / n \quad (5)$$

$$q_r = c_p \sum_{i=1}^n CDH_i / n \quad (6)$$

The internal air thermal parameters are also assumed as temperature of 26 °C and relative humidity of 65%. CDH_i , CWH_i and $VSHR$ during June, July, August and September (2928 hours) are calculated for 208 cities in different areas. Fig.3 shows the characteristics of fresh air thermal loads of 11 typical cities.

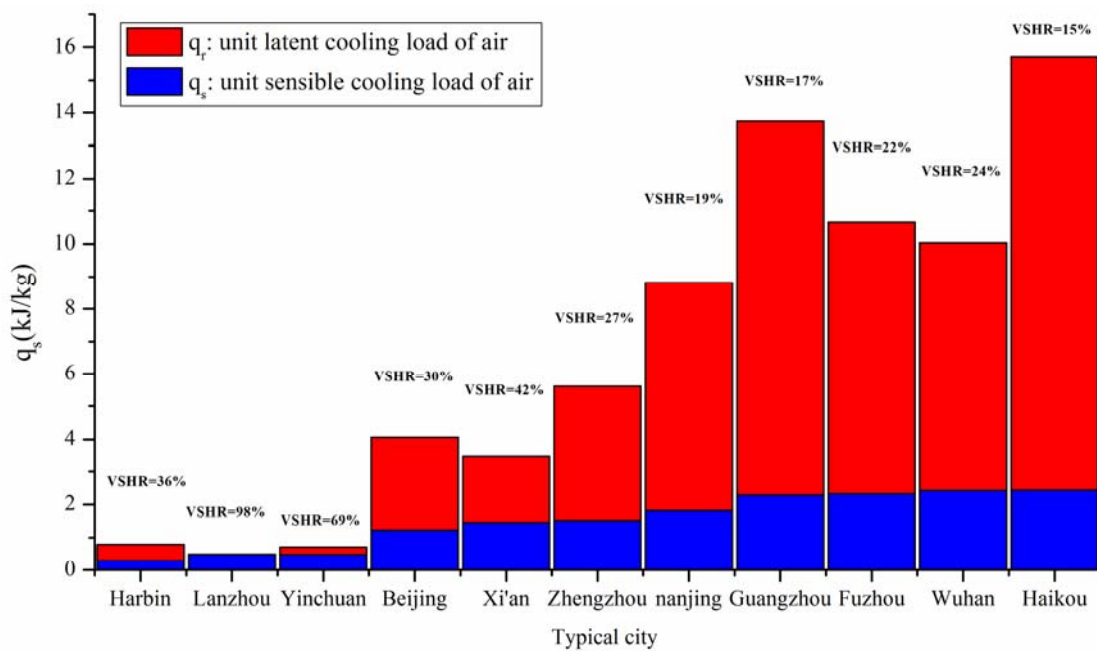


Figure 3. The characteristics of fresh air thermal loads in different cities

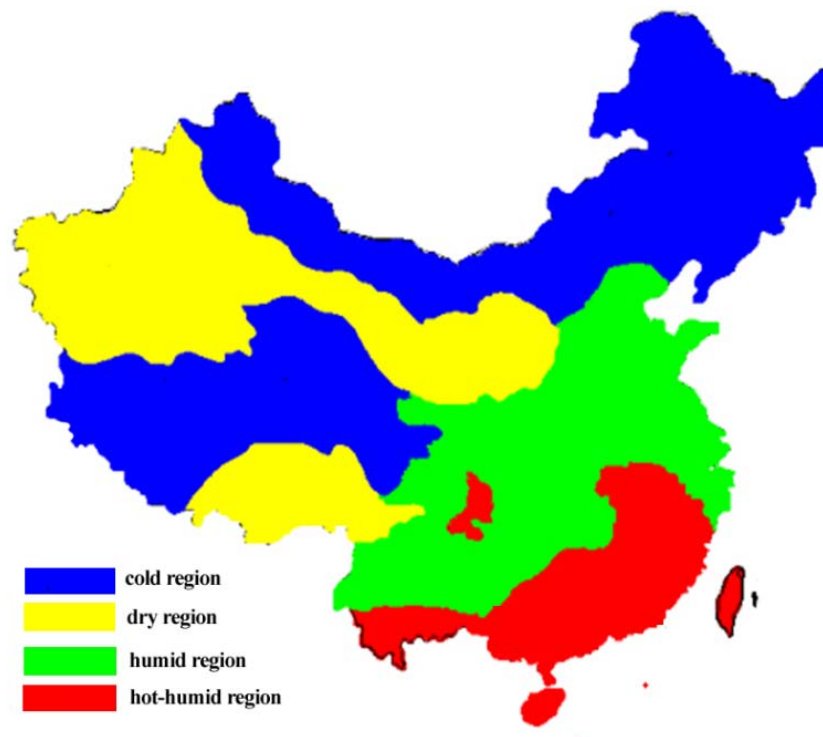
In Fig.3, the $VSHR$ in Lanzhou is 98%, which means that the loads are basically sensible cooling loads and low air moisture in this region. The values of $VSHR$ in Nanjing, Guangzhou and Haikou are below 20%, it indicates moist climate in these areas. Relative humidity plays a vital role on the thermal environment for underground engineering. $VSHR$ reveals the air moisture in different regions and therefore it should be considered as an important index for the climate zones.

3. Climate zones

With the foundation model given in Table 1, the T_g and $VSHR$ for underground engineering in 208 typical cities are calculated to establish the climate zones for underground engineering. The climate indices are prepared by using clustering analysis for the different typical cities and Euclidean distance is adopted to determine the similarity between the classes. Too many climate zones are not good for referencing and therefore not suitable for designers. Similarly too few climate zones are also not appropriate to depict the thermo-technical differences in different regions. Considering the practical applications, the underground engineering in the China is divided into four climate regions: Cold (C), Dry (D), Humid (H) and Hot-Humid (HH) as shown in Fig.4. The values of indices for main factors are shown in Table.2.

Table 2. The values of indices of thermal divisions

Thermal division	Indices	
	T_g	VSHR
cold region	$T_g < 11.5^\circ\text{C}$	—
dry region	$T_g > 11.5^\circ\text{C}$	VSHR > 40%
humid region	$11.5^\circ\text{C} < T_g < 19^\circ\text{C}$	VSHR < 30%
hot-humid region	$T_g > 19^\circ\text{C}$	VSHR < 25%

**Figure 4.** Climate zones for underground engineering in China

China has a very broad geographical area and therefore having large differences of thermal environment parameters in different regions. The large variations can also be seen from the annual mean ground temperature, which are 5.4°C , 13.4°C and 23.8°C in Harbin, Beijing and Guangzhou, respectively. However, the current underground design standards ignore such differences in the engineering practices. Based on the climate zones map, the energy conservation designs and analysis could be conducted specifically for underground engineering in different areas.

4. Conclusion

The purpose of this research is to establish reasonable climate zones for underground engineering. Typical indices including T_g and VSHR for underground engineering in 208 typical cities are calculated, and four climate zones including Cold, Dry Humid and Hot-Humid are established. The energy conservation designs and analysis could be conducted specifically for underground engineering in different climate zones.

Acknowledgments

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