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The Climate and Atmospheric Cleanliness of Underground Public Construction in Chongqing

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ABSTRACT

This paper discusses the present situation of underground public construction in Chongqing, China, a mountain city with high humidity, including the design scheme, handling process, system, airflow form, and equipment for air conditioning. The heat and moisture loads, energy conservation measures, and operating expenses of the equipment are presented. In addition, the indoor air temperature, humidity, velocity, and level of noise are determined, as well as bacteria content in air. The operational situation and human health conditions in such space are evaluated.

INTRODUCTION

Underground construction in Chongqing started in the early 1940s. Man-made or natural caverns were used for shelters, workshops, warehouses, or machine rooms. In order to enhance the social and economic benefits of utilizing underground space, in recent years complex markets, exhibition halls, hotels, hospitals, restaurants, dance halls, amusement rooms, auditoriums, and warehouses have been built there. Usually, such structures are situated in urban areas in reconstructed old tunnels and are connected with above-ground buildings. Therefore, both economic and social benefits could be gained. However, the architectural planning and indoor and outdoor environment were restricted.

Chongqing is a mountain city situated in a region with high temperature and humidity. The seasons are distinct, and in summer, the dry- and wet-bulb temperatures of the outdoor air are high. The soil is of the sandstone and shale type with an abundance of permeated water. There is no low-temperature groundwater to be used. All these are environmental characteristics faced by the air-conditioning engineer. A review of the practice of underground engineering in Chongqing can promote improvement of the indoor environment and save operating expenses and investment.

THE TYPES OF AIR CONDITIONING

In the early days, natural ventilation was applied in underground construction in Chongqing. Later, mechanical ventilation was applied with heating and dehumidification. In recent years, with the development of public structures, various types of air conditioning have been applied, which can be summarized as follows:

1. Natural or mechanical ventilation (for caverns of small depth).
2. Natural ventilation with dehumidification by chilling, etc. (for a deep and low cavern with little demand for indoor temperature and humidity control).
3. Central air-conditioning systems with primary return air and reheating.
4. All-air induction air-conditioning systems.
5. Fresh air introduced into a tunnel and dehumidified and cooled by air-conditioning units.

When reconstructing old underground tunnels, the authors were responsible for two experimental air-conditioning projects. Project A was an exhibition hall for goods of daily use with a working area of 890 m^2. Due to an irregular plan and variation in room size, the main corridor connecting with the urban underground passway is low, so the air-conditioning scheme shown in Figure 1 was applied.

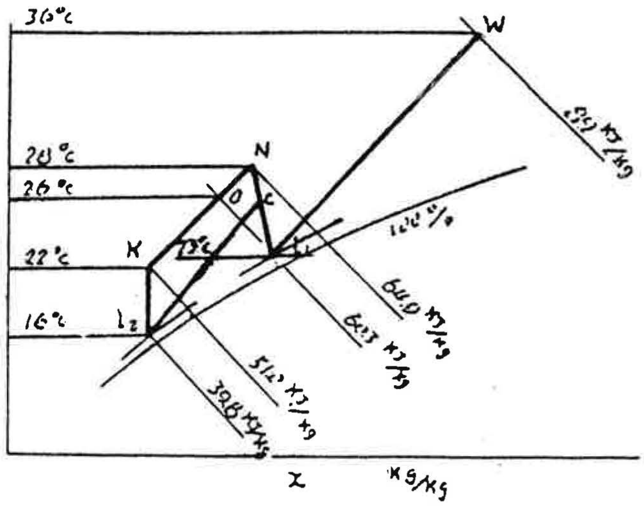

Figure 1 Process of air treatment in summer

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In order to reduce the fresh air load, outdoor air is cooled and dehumidified by passing through an underground tunnel (w – L_1), then mixed with return air at point C, after being filtered, chilled, and dehumidified at point L_2, and heated at point K. After that, it is transmitted by a high-velocity duct into 32 all-air induction units placed in a service area mixed with secondary air (N) at point 0. The primary return air flows back to the mixing chamber through the corridor.

To eliminate noise in the room, a silencer for intake and return air was installed. The flow rate and induction ratio (n = 2) are controlled. In the air-conditioning unit, air cooling is combined with water cooling, and the air-cooling condenser is used as an air heater.

In underground hospitals and hotels, the bushing structure usually is applied. There is sound insulation for walls and ceilings. There is a false window on the wall and the visual sense of inhabitants is regulated by lighting. Considering the small size of such construction at present and the characteristic heat and moisture loads, fan and coil systems are not yet applied. Mostly central air conditioning is used. The measures for energy conservation and investment saving are similar to those in project A.

In this type of construction (such as Project B), fresh air is supplied to rooms through brick or steel ducts arranged under the arch and returned to air-conditioning units through corridors.

In recent years, ventilation without ducts has become popular in underground markets, clubs, etc. In such a system, the service space is used as a return-air duct. The initial investment for that is low (see Figure 2). To eliminate local temperature differences caused by longitudinal airflow, a large air volume for circulation is applied for the air-conditioning system, and the number of air exchanges may be as much as 30 cycles per hour. Due to low resistance of the airflow, the power for the fan is not large.

THE INDOOR LOAD

The temperature of bedrock in Chongqing is 20.1 °C, which is lower than the indoor temperature in summer and heat transmission for an enclosure is negative. Therefore, the indoor load in underground public structures comes mainly from humans and the heat emission of lighting.

It can be seen from the instantaneous indoor cold load given in Table 1 that the designed indoor cold load in an underground dining hall or business hall is lower by 15%-25% than that of above-ground construction of the same type. In a vestibule or a guest room, where occupancy is rather low, the indoor load is lower by 47%-83% than in ground structures with large glass windows. As far as the operating expense for air conditioning is concerned, the underground construction is more advantageous.

THE FRESH AIR LOAD

The air-conditioning load in a public structure usually is composed of the indoor load, fresh air load, and the load for temperature rise in fan and duct. The load for the fan is no more than 10 W/m^2. Due to the low temperatures in underground construction, the load for temperature rise in the duct is also low.

Due to the hot and humid climate in Chongqing's summer, the cooling load of fresh air is rather high. As shown in Table 2, the fresh air load in a dining hall can be as high as 50% of the total cooling load. For other rooms, it is 30%-35%. In order to cut the operating expenses, it is important to control the volume of fresh air.

According to estimates made by the authors in 1984 (Table 3), the cumulative hours of outdoor temperature exceeding 25 °C in Chongqing are rather long and the annual power consumption for cooling fresh air is high, so it is important to have rational choices for indoor temperature and moisture level.

In Chongqing, the outdoor temperature in winter is rarely below 0 °C, and according to custom it is preferable to have a rather low indoor temperature in public buildings. The heater is rarely used in winter. The results of measurements show that, based on heat transmission from an enclosure and heat emissions by humans and lighting, the room temperature can be kept at 13 °C-16 °C.

CHARACTERISTICS OF THE SYSTEM

Due to a deduction of the cooling load of sensible heat in underground construction and the existence of moisture emis-

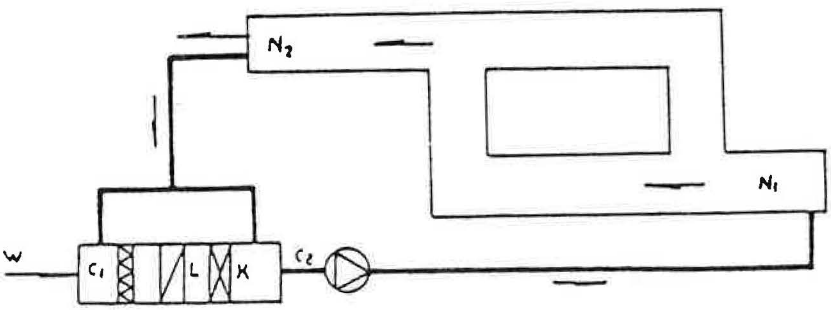

Figure 2 Schematic diagram of an air-conditioning system for a market

TABLE 1
The Mean Indoor Instant Cooling Load at 12:20 p.m. in Designed Performance for Summer

Type of room		Business hall	Dining hall	Vestibule	Guest room	
Indoor temperature °C		27	25	27	26	
Illumination W/m^2		30	40	20	20	10
Room occupancy p/m^2		0.4-0.8	0.8	0.19	0.14	0.14
Cold load W/m^2	Ground building	100-152	167	160	92	80
	Underground construction	82-125	133	30	48	35

TABLE 2
Fresh Air Load and Cooling Power Consumption for Air Conditioning in Designed Performance of Some Underground Construction in Summer

Type of room	t_N °C	ϕ_N %	Volume of fresh air %	Load of fresh air m^3/h p	Cooling power consumption W/m^2
Business hall	27	65	12	40–65	130–200
Dining hall	26	60	17	145	290
Office	28	65	17	30	85
Guest room	26	65	25	26	75

Note: For office the room occupancy 0.21 p/m^2, illumination 23 W/m^2
For other rooms as in Table 1

TABLE 3
Annual Cooling Power Consumption of Fresh Air (1984)

t_N °C	28				25			
ϕ_N %	65	60	55	50	65	60	55	50
Cumulative hours in a year h	1641	2287	2836	3130	3130	3406	3586	3766
Cooling power for fresh air per kg a year kW·h	2.78	5.22	7.58	10.4	10.5	12.8	16.0	18.1

Note: Figures given for operation all day round.

sions from rock walls, the indoor heat/moisture ratio in summer for public buildings is usually in the range of 4800-6000 KJ/kg. It is further reduced by air conditioning. The air-conditioning system with reheating of primary return air is used. To simplify the duct network and save building volume, the air is cooled by a surface cooler with direct evaporation,

The stratum in Chongqing is composed of rock, and fresh air can be taken only from a shaft, entrance, or unused cavern. Experience shows that the incorrect choice of an air intake position will have an adverse effect on the cleanliness of the indoor air.

The duct for underground construction is usually made without an insulation layer, Due to high relative humidity under initial indoor conditions, the duct was damaged seriously in early projects. Since 1965, the authors have applied epoxy zinc-enriched paint for coating ducts in places of high humidity. This has proven successful.

The fans in underground construction operate year-round and the background noise is low, so it is important to have reasonable choices of pressure, silencer for intake and return air, and sound insulation for duct and machine room.

Because the underground construction in is deep and the entrance is long, condensation is liable to occur in summer. So it is reasonable to have an airflow curtain at the entrance with mechanical exhaust.

APPLICATION OF DEHUMIDIFIER WITH TEMPERATURE REGULATION

The dehumidifier with temperature regulation is a unit where the air- and water-cooling condensers are used together and the air-cooling condenser is also used to reheat the air. According to measurements carried out for Project A, the outlet temperature of a machine with air cooling is about 32°C-34°C, with relative humidity of 41%-46%. The temperature of the intake air is 22°C-24°C, and its relative humidity is 84%-94%. There will be 32 kg/h moisture removed per 1,000 kg/h air. The indoor temperature and humidity under continuous operation are shown in Table 4.

Usually the operation management during transition season is neglected. When the outdoor temperature is about 20°C, people wear more clothes and feel muggy when entering an underground structure. At this time, it is reasonable to reduce the volume of reheating and lower the dew point of the machine for the indoor temperature, and the temperature at the entrance can correspond to variations of the outdoor temperature.

APPLICATION OF ALL-AIR INDUCTION UNITS

In an all-air induction unit, there is no need for a secondary coil. The duct size is small and it is easy to balance air volume. So such a unit can still be used in reconstruction of underground projects with small indoor heat and humidity loads.

TABLE 4
Indoor Temperature and Humidity under Continuous Operation of Air-Conditioning System

Operation time h	0	1	3	5	7	10	15	20	25	30
t_N °C	22.3	24.8	25.6	25.2	25.8	25.8	26.0	26.3	27	26.9
ϕ_N %	94.7	70.0	55.9	56.4	56.2	57	56.3	56.6	53.3	53.2

Because the indoor airflow is semi-transverse and the primary return air comes back to the machine room through the corridor, there will be a vertical gradient in temperature and humidity. In Project A, for example, there is an exhibition hall with an area of 35 × 7 m. The indoor temperature rises along the direction of the return flow. The temperature at the final point is 26.7°C or 1.4°C more than at the starting point and the relative humidity has decreased from 57% to 54.8%. Many surveys have shown that the local temperature difference in the room is no more than 1.5°C and for the relative humidity, no more than 10%. If the number of air exchanges is n = 20 c/h, the airflow rate in the working area is 0.1-0.4 m/s, on average 0.22-0.29 m/s.

The key point for desiring such a system is to reduce noise in the induction unit. The total sound level, as shown in Table 5, is in the range of 44 to 51 dB(A). Investigation shows that reduction of the air supply rate and airflow rate at the nozzle and increase of indoor sound absorption are beneficial for reducing the noise level. On condition that the background noise level is no more than 23 dB(A), such a system is unsuitable for residential use.

APPLICATION OF TUNNEL AIR

The survey shows that the outdoor air, after being cooled in the underground tunnel, will give saturated air of 23°C-24°C. The enthalpy of fresh air will be reduced by 11.5-18 kJ/kg, and moisture content will be reduced by 0.2-1.9 g/kg. Therefore, the primary investment for the air-conditioning units and annual operating expenses for the transformer will be cut down. However, due to the long transition season in Chongqing, the air temperature in the underground tunnel can still reach 21°C-22°C. From the viewpoint of energy conservation, it is beneficial to use outdoor air directly. To overcome this disadvantage, the outdoor air can be delivered through the shaft near the machine room.

In the underground tunnel, there is often a great deal of dust remaining from blasting, which is a favorable environment for insect and bacteria reproduction. It is also liable to absorb harmful gas from neighboring construction. So the application of underground tunnel air should be considered carefully.

ATMOSPHERIC ENVIRONMENT

The temperature and humidity in underground public structures in Chongqing can roughly meet the requirements of comfort and service. The concentration of CO_2 in the air usually is less than 0.15%. The intensity of illumination is less than 85% of the standard and radiation is in the range of 7.5-9.75 μR/h. The noise level in the market is sometimes as high as 75-83 dB(A). The dust content and number of bacteria in the air exceed what is permitted by standards (Table 6). The concentrations of radon and its progeny remain to be determined.

In the center of Chongqing, the duct content and number of bacteria are very high by day. The cleanliness of the street needs to be improved. So it is necessary to ensure mechanical exhaust at the entrance, filtering of fresh return air, reduction of dust carried by shoes, and improvement of airflow.

OPERATION

Air-conditioning systems in the underground construction of Chongqing are operated intermittently for ease in control

TABLE 5
Indoor Noise Level of Induction System (Project A)

Room	Central frequency of frequency doubling range (Hz)									Total noise level (dB)			
	31.5	63	125	250	500	1 K	2 K	4 K	8 K	A	B	C	Linear
1	58	54	50	44	41	44	38	35	30	47	52	61.5	51
2	60	53	42.5	44	39	42	34	30	25	44	50	61	80
3	53	55	54	48	46	47	43	39	31	51	55	67	64

TABLE 6
Air Quality in Project C (1990)

Date	10 Jan.	11 February		3 March		26 July	
Time	7:30	8	15	8	15	8	15
Total number of bacteria 5 min. exposure x 10^3 /m^3	1.5-7.2	0.7-2	21-100	0.8-7.8	22-140	0.5-8.1	4.4-50
Number of pathogenic bacteria (20 min. exposure) x 10^3 /m^3	0.8-33	0.5-1.8	6.5-38	0.7-2.6	1.3-57	0-1.3	0-9.1
Concentration of CO_2 10^{-2}%	3-4.4	3.8-57	7.5-14.2	3.4-9.7	3.4-9	3.6-4.2	6-8
Dust content mg/m^3	0.31-0.85		2.2-3.9		0.6-0.7	0.2-1.0	
Inhaled dust 10^{-1} mg/m^3	0.8-6		11-20.5		1.8-2.4	0.23-0.4	

and energy conservation. Usually the operating time is 8 to 12 hours a day. Practice shows that its performance is good. The authors have made several measurements of indoor temperature and humidity for Project A. Although the relative humidity at night was as high as 90%-95%, no hydrolysis, aging, corrosion, or deterioration of goods occurred, and the equipment was in normal state.

BENEFITS

In recent years, many old caverns have been renovated and used again. These caverns are situated in the central part of the city and are connected with above-ground buildings, so the rate of utilization is quite high. The customer flow in the business hall exceeds 9×10^3 people per hour.

Due to economic benefits, no tax, and other favorable policies and with the power consumption for air conditioning in the range of 15-30 W/m^2, it is accepted by clients, and the initial investment can be recovered in a short time.

PROBLEMS AND COUNTERMEASURES

Many problems were revealed and some experience gained during design of the underground structures.

1. Utilization of underground public construction should be considered in accordance with economic benefits and human psychology. Reduction of room occupancy in the hotel indicates that people are difficult to please in an underground dwelling, so such construction should preferably be used where people stay for short time.

2. Dehumidifiers with temperature regulation, natural ventilation, and intermittent operation are all good ways to conserve energy but the air-conditioning schemes are monotonic. Natural energy resources remain to be used.

3. Attention was paid to the indoor climate and concentration of CO_2, but air quality still needs to be improved. In some places, the dust content and number of bacteria do not conform to standard. Thirst, swelling of the throat, and respiratory tract discomfort occurred, and the design and management should be improved.

4. Fresh air is likely to be polluted in the tunnel, and it is uneconomical to use during the transition season. Attention should be paid to the application of tunnel air.

5. Nonduct ventilation has some merits, but its hygiene and fire resistance should be improved.

6. The optimum manner of controlling the operation during the transition season remains to be investigated.

7. The septic tank is often placed in the tunnel, and a suction pipe for exhaust should be put into the tank.

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