CHEMICAL ENGINEERING TRANSACTIONS

VOL. 62, 2017

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216

DOI: 10.3303/CET1762100

Study on Correlativity of Influencing Factors of Tunnel and Solar Chimney Ventilation Composite System

Liang Wang*, Zhijian Zhang

School of civil engineering and architecture, Southwest University of Science and Technology, Mianyang 621010, China
wangliangmy83@163.com

The two types of passive system, the tunnel ventilation and the solar chimney ventilation, are combined to adjust the indoor thermal environment and it can fully realize the optimized utilization of renewable energy resources. In this paper, through the establishment of tunnel and solar chimney ventilation composite system model, study on the correlativity of influencing factors of the tunnel length, the ratio of tunnel air inlet to solar chimney area, the height of the solar chimney and soil type etc. The results show that the maximum value of soil type is the highest, when reaching 2.90, indicating the greatest influence on indoor temperature. When optimizing the design of ventilation composite system, the adaptability of local soil to the system should be given priority. If the soil type cannot meet the demand of the heat exchange of the tunnel ventilation system, the method of selecting the appropriate diameter and increase the length of tunnel can be achieved. When the tunnel length is 3 times the length of the room and the soil is marble, the air temperature will decrease by 4 degrees after the cooling of the tunnel.

1. Introduction

In recent years, the tunnel ventilation system has been successfully used in hospitals, greenhouses, schools and many other public buildings, which significantly reduces the increasing energy consumption of buildings. The tunnel ventilation system mainly uses geothermal energy stored in the soil to cool or heat outdoor air. Through the mechanical air supply or inductive ventilation, the treated air is sent into the room to reduce the energy consumption of the building's air-conditioning and improve the thermal comfort of the indoor environment. It has good energy saving effect and environmental benefits. In the development of tunnel wind technology, many scholars have carried out the thorough research on this technology. Goswami (1993) uses an open loop air duct to test the performance of the soil air system and measures the exit temperature of the air when the outdoor air temperature changes. And put forward the main factors influencing the outlet air temperature, such as the original formation temperature, pipe diameter, pipe length, air velocity, wind power machine etc. Through the steel pipe and the PVC tube contrast experimental research, Bansal discovered that the tunnel material has little influence on the heat transfer effect (Bansal V, et al. 2010,). On the basis of three-dimensional solid unsteady heat conduction model and one-dimensional fluid heat conduction model, Song Ling has taken into account the influence of heat transfer between tube and tube and used finite difference method to establish a multiple tunnel cooling heat transfer model (Ascione et al., 2011,). Kato and others have carried out field test experiments on tunnels, and proposed the idea of dynamic simulation of air flow in tunnels by using CFD calculation method (Kato et al., 1997). Krarti et al. (1996) assumes that the heat transfer system is in a stable state and studies the energy saving effect of the soil-air heat transfer system by using a periodic model. The influence of heat and moisture transfer on latent heat and sensible heat load of different building materials commonly used under different boundary conditions is investigated by Mendes (Mendes N, et al. 2003). For the study of composite tunnel systems, Bansal proposed adding evaporative cooling devices at the end of the tunnel system to provide a comfortable indoor environment for further cooling. In hot and dry areas, combined with evaporative cooling system, the cooling system has more advantages (Bansal et al., 2012). Maerefat and Haghighi (2010) proposed the combination of two passive systems, the tunnel wind and the solar chimney, should be applied to building ventilation and cooling. Harris and Helwig (2007) have proved that the ventilation efficiency of the roof solar chimney is better than that of the vertical collector roof solar

Please cite this article as: Liang Wang, Zhijian Zhang, 2017, Study on correlativity of influencing factors of tunnel and solar chimney ventilation composite system, Chemical Engineering Transactions, 62, 595-600 DOI:10.3303/CET1762100

chimney. Ylidiz et al. (2012) combines the photovoltaic power generation system with the closed tunnel air system, and the photovoltaic power generation system takes part of the power consumption of the fans, which can greatly reduce the power consumption of the peak system. Mathur studied the solar-chimney-induced ventilation system, and concluded that the inclination angle of the absorption tower would influence the ventilation volume of the ventilation system (Mathur et al., 2006)

In summary, in the process of research on tunnel ventilation system, by studying the influencing factors of the heat transfer effect of the tunnel ventilation system, the compound ventilation system is optimized, and the factors affecting the cooling capacity of the tunnel air system are obtained. On the basis of the existing domestic and foreign research on tunnel cooling project, a numerical model of combined ventilation system of tunnel and solar chimney is established on the basis of meteorological and geological conditions in Sichuan. Study on the correlativity of influencing factors of the tunnel length, the ratio of tunnel air inlet to solar chimney area, the height of the solar chimney and soil type etc. The method of orthogonal simulation is used to analyze the effect of indoor cooling, and the system is optimized to provide reference for people in practical engineering design.

2. Model building

The average dry bulb temperature of outdoor air in summer in Sichuan is 31.8 ºC, outdoor average wind speed is 1.1m/s, and atmospheric pressure is 94.8kPa. In accordance with the meteorological conditions, the numerical simulation is carried out, and a model of ventilation system of tunnel wind and solar chimney is established. The shape of the tunnel is circular, as shown in Figure 1. Of which the size of the room model is 5m * 4m * 3m, the tunnel point of the depth of 3.5m, the solar chimney cross-sectional size of 2m * 1m, and the side of the solar chimney is a glass. The sunlight passes through the glass to heat the air inside the solar chimney and causes pumping by buoyancy, which cools the outdoor fresh air into the room from the air inlet. At the same time, the indoor hot air will be discharged from the top of the solar chimney, so that the air flow inside the building will eventually achieve the purpose of indoor ventilation and cooling.

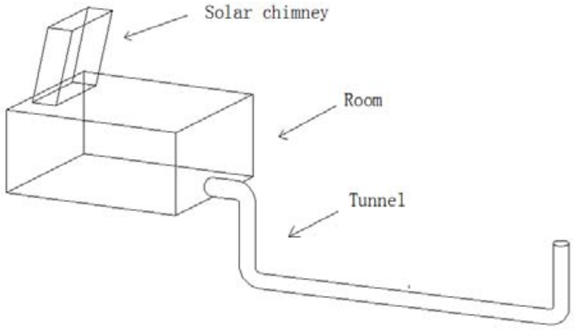


Figure 1: Model of ventilation compound system for underground wind and solar chimney

3. Orthogonal simulation experiments

3.1 Experimental model parameter setting

According to all that the above formula said, approximately consider that the convection heat transfer coefficient of the air in the tunnel remained constant throughout the length direction. The air flow in the tunnel is turbulent. The buried depth of 3.5 m is calculated and the soil temperature outside the pipe wall is 19.19 ºC. The heat flux on the surface of the solar collector board is set as 400 W/m2. The inlet is set as pressure inlet, the inlet air pressure is 0 Pa, the inlet temperature is 31.8 ºC, and the turbulence intensity is 2 %. The outlet is the pressure outlet, the outlet pressure is 0Pa, and the backflow turbulence intensity is 2 %. In addition, the numerical model is discretized via a non-coupled implicit non-equilibrium wall function algorithm, and the two-order upwind difference scheme is used to discretize the energy equation, momentum equation and turbulent energy equation.

3.2 Indoor temperature orthogonal simulation experiment

In order to improve the adaptability of the tunnel and the solar chimney ventilation system, in this paper, an orthogonal simulation method is used to determine the optimum test scheme of the system. According to the tunnel length, the ratio of the air inlet to the outlet area, the height of the chimney and the soil type, the influence of 4 factors on the indoor temperature (this paper mainly measures the temperature at the indoor 1.1m). The level of each factors takes for 3, ignoring the interaction between factors, the factors were randomly arranged to obtain the level of orthogonal simulation of each factor, as shown in Table 1. In the process of simulation, the tunnel's horizontal lengths are measured by 3, which are 1 times, 2 times, and 3 times the length of the room.

Table 1: Orthogonal experimental factor

Level value	Tunnel length /m	The ratio of the air inlet to the outlet area /(m^2*m^{-2})	The height of the chimney /m	Soil type
Level 1	5	0.4	2	Shale (λ=0.835W/m•ºC)
Level 2	10	0.8	3	Sandstone (λ=1.838 W/m•ºC)
Level 3	15	1.2	4	Marble (λ=3.849 W/m•ºC)

In the above table, the tunnel length, the ratio of the air inlet to the outlet area, the height of the chimney and the type of soil are the 4 factors in the experimental study. They are denoted as A, B, C and D respectively. According to the orthogonal simulation test and to ensure any level of any factor at any level and other factors are the premise and only once the collision, the experimental parameters and calculation results of indoor temperature orthogonal simulation test are shown in Table 2. I is the sum of the experimental results corresponding to level 1 of the corresponding column. II is the sum of the experimental results corresponding to level 2 of the corresponding column. III is the sum of the experimental results corresponding to level 3 of the corresponding column. T is the range value of the indoor temperature orthogonal simulation test results, which reflects the influence degree of each factor on the test result.

Table 2: Indoor temperature orthogonal simulation test

Test number	tunnel length /m	the ratio of the air inlet to the outlet area /(m^2*m^{-2})	the height of the chimney /m	Soil type	indoor temperature/ ºC
1	5	0.4	2	shale	30.64
2	5	0.8	3	sandstone	30.26
3	5	1.2	4	marble	29.77
4	10	0.4	3	marble	29.25
5	10	0.8	4	shale	30.17
6	10	1.2	2	sandstone	30.53
7	15	0.4	4	sandstone	29.29
8	15	0.8	2	marble	28.87
9	15	1.2	3	shale	29.98
I	90.67	89.18	90.04	90.79	——
II	89.95	89.30	89.49	90.08	——
III	88.14	90.28	89.23	87.89	——
T	2.53	1.10	0.81	2.90	——

As shown in Table 2: (1) TD>TA>TB>TC. Therefore, soil type and tunnel length are the main factors that affect the indoor temperature. The ratio of the area of the main entrance to the solar chimney and the outlet area of the chimney is a secondary factor. As a result of TD>TA, the influence of soil type on indoor temperature is greater than tunnel length. Therefore, in the process of system design, priority should be given to the adaptability of soil types to the system. Secondly, the influence of tunnel length on the system should be considered. (2) TC is much smaller than TA and TD, which indicates that chimney height has little influence on indoor temperature, and can even be neglected. (3) For tunnel length, the IA, IIA, and IIIA decrease successively, indicating that the indoor temperature gradually decreases with the increase of tunnel length. This is because, as the length of the tunnel increases gradually, it takes longer time for the air to pass through the tunnel, the more heat it will have with the tunnel, which leads the lower the air temperature into the room eventually. (4) Different soil types lead to different wall heat transfer coefficients. By ID, IID, IIID gradually decreasing trend can be seen, with the increase of soil thermal conductivity, the capability of mitigation of soil temperature fluctuation is stronger, and the soil cooling ability is better, the colder air makes the final, leading to the indoor temperature gradually decreased. (5) When the solar chimney area is constant, the larger the area ratio between the main air inlet and the solar chimney, the greater the diameter of the chimney. As can be seen from table 2, IB<IIB<IIIB shows that the room temperature increases gradually with the increase of

the pipe diameter. Therefore, in the optimization design of the ventilation composite system, the tunnel bore diameter should not be too large.

Tunnel length is one of the main influencing parameters of cooling capacity of combined ventilation system of tunnel wind and solar chimney. The longer the tunnel length, the better the cooling capacity of the system, but the area ratio of the main air inlet and the solar chimney outlet and the thermal conductivity of the soil will also affect the cooling capacity of the system. Set parameter: buried depth of the buried pipe is 3.5 m, the tunnel diameter is 1m, the air inlet temperature is 31.8 ºC, and the tunnel length is from 0 to 15 m. According to the above parameters, the indoor temperature drops the ventilation composite system of the tunnel and the solar chimney under different soil conditions are calculated, as is shown in Figure 2.

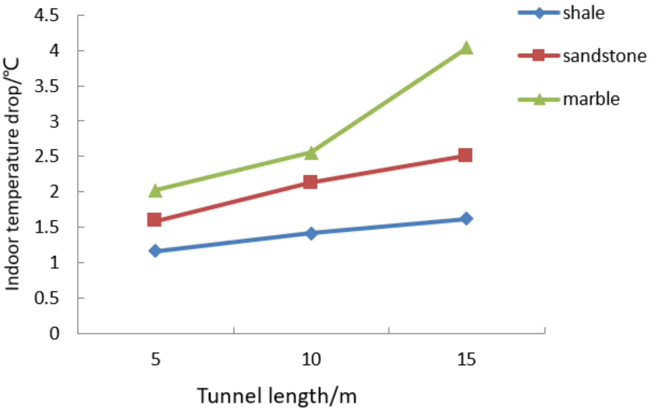


Figure 2: Inlet air temperature drop at different pipe length

As we can see from Figure 5, when the tunnel length was 5 m, 10 m, 15 m, Shale soil temperature decreased by 1.16 ºC, 1.41 ºC, 1.62 ºC, the soil temperature in sandstone decreased by 1.59 ºC, 2.13 ºC, 2.51 ºC, the soil temperature of marble decreased by 2.02 ºC, 2.55 ºC,4.04 ºC. From the above data it can be found that, with the increase of the length of the tunnel, tunnel ventilation system and solar chimney composite indoor temperature gradually decreased. When the length of tunnel is 5 to 10 m, the indoor temperature drop ratio of the three kinds of soil is roughly the same. When the length is greater than 10m, the indoor temperature of marble soil decreased obviously. This is because with the increase of soil thermal conductivity, the better the soil's ability to alleviate the temperature fluctuations, the more heat the air transfers to the soil, and the cooling effect of the air is enhanced. So, in the optimization design of the wind tunnel and the solar chimney composite ventilation system, to ensure that the indoor temperature can meet the comfort temperature of the human body under the premise, priority should be given to the adaptability of soil system, then to the increasing the length of the tunnels, which is more than 3 times the length of the room.

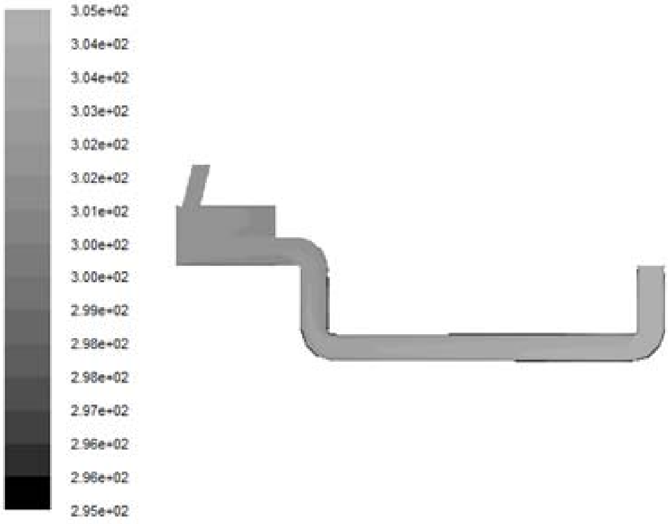
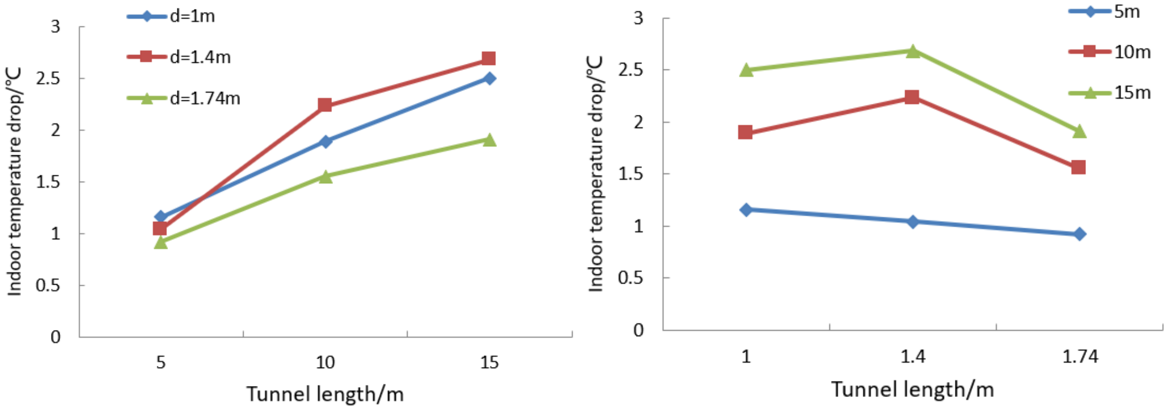


Figure 3: Section of temperature contour

In order to study the thermal comfort of indoor environment, test 8 is selected in Table 2 and simulated by CFD software. The simulation results are shown in Figure 3. Combined with data coordinates and temperature nephogram, it can be seen that the temperature of indoor active area is 28.5~29 ºC. As the body's "heat tolerance" upper limit temperature can be defined as 26~29 ºC, so for human thermal comfort, the air supply temperature can basically meet the comfort requirements of the human body.

In addition, in order to further study the effects of tunnel length, the ratio of tunnel air inlet to solar chimney area on cooling capacity of combined ventilation system of tunnel and solar chimney, taking experiment 1 in table 2 as the research basis, without considering the soil conditions, setting the tunnel length of 5 m, 10 m, 15 m, tunnel diameter 1 m, 1.4 m, 1.87 m respectively. Then, the indoor temperature drop rate of the tunnel heat exchange system is simulated according to different pipe diameters. And the simulation results are shown in Figure 4(a) and (b).



(a) (b)

Figure 4: (a) Indoor temperature drop at different tunnel length; (b) Indoor temperature drop at different diameter

As can be seen from Figure 7 (a), with the increase of tunnel length, the indoor temperature decreases gradually. When the tunnel length is 5 m, there is little difference in the temperature between the 3 pipe diameters. When the pipe diameter is 1.4 m, the tunnel length increases from 5 m to 10 m, the indoor temperature decreases greatly, and the cooling effect is obviously higher than another diameter. As can be seen from Figure 7 (b), the diameter increases gradually, and the indoor temperature increases first and then decreases. When the pipe diameter is 1m, with the increase of tunnel length, the indoor temperature drops by 1.16 ºC, 1.89 ºC, 2.50 ºC. When the diameter is 1.4m, the indoor temperature drops by 1.04 ºC, 2.23 ºC, 2.68ºC. When the diameter is 1.87 m, the indoor temperature drops by 0.92 ºC,1.55 ºC,1.91 ºC. According to the above data, when the pipe diameter is 1.4 m and the tunnel length is increased from 5 m to 10 m, the air temperature drops from 1.04 ºC to 2.23 ºC degrees, with the largest drop rate. When the diameter is greater than 1.4m, the indoor temperature drops to 2.68ºC, and the proportion decreases. This is because, as the pipe diameter increases, the inlet wind speed gradually decreases, and when the inlet wind speed cannot overcome the pipe resistance, the air and tunnel heat transfer effect will decline, and eventually lead to the indoor air temperature drops little. It can be concluded that when the soil type cannot meet the demand of the heat exchange of the tunnel air system and needs to obtain a lower final temperature, the method of choosing the proper diameter and increasing the tunnel length can also be achieved.

4. Summary

This paper mainly established a three-dimension steady-state model of tunnel and solar chimney ventilation composite system. Study on the correlativity of influencing factors of the tunnel length, the ratio of tunnel air inlet to solar chimney area, the height of the solar chimney and soil type etc. The influence of different factors on the cooling capacity of the system was studied by the orthogonal simulation test and drawing the conclusions.

(1) According to the orthogonal simulation test, the length of tunnel and the type of soil are the main factors affecting the cooling and heat transfer capacity of combined ventilation system of tunnel and solar chimney. Through range analysis, the soil type extreme value is 2.90, and the tunnel length and range value are 2.53. It shows that the influence of soil type on indoor temperature is greater than that of tunnel length.

(2) As the length of the tunnel increases, the longer the air passes through the tunnel to the room, the better the cooling effect of the tunnel. In addition, the different types of soil lead to different heat transfer coefficients. The greater the thermal conductivity of soil, the stronger the soil's ability to alleviate the temperature fluctuations, and the colder it can supply to the air, the greater the drop-in room temperature.
(3) When the ratio of the outlet area to the solar chimney and the height of the solar chimney are certain, the influence of different soil types on indoor temperature is different. When the tunnel length is 3 times the length of the room and the soil is marble, the indoor cooling effect is the best, and the air temperature after the tunnel cooling is reduced by about 4ºC. Therefore, the adaptability of local soil quality to the cooling capacity of the system should be taken into account in the optimization design of the tunnel combined ventilation system.
(4) When the soil type cannot meet the demand of the heat exchange of the tunnel ventilation system and needs a lower final temperature, it is also possible to choose the proper diameter and increase the tunnel length. When the diameter is 1.4m, length is 15m, there is the largest range of decline in the indoor temperature, which can be reduced by 2.68 ºC.

Acknowledgments

This work has been supported by Research Fund for PHD of Southwest University of Science and Technology (Grant No13zx7110).

Reference

Ascione F., Bellia L., Minichiello F., 2011, Earth-to-air heat exchangers for Italian climates, Renewable Energy, 36(8), 2177-2188. DOI: 10.1016/j.renene.2011.01.013.

Bansal V., Mishra R., Agarwal G.D., Mathur J., 2012, Performance analysis of integrated earth–air-tunnel-evaporative cooling system in hot and dry climate, Energy & Buildings, 47(47), 525-532. DOI: 10.1016/j.enbuild.2011.12.024.

Bansal V., Misra R., Agrawal G.D., Mathur J., 2010, Performance analysis of earth–pipe–air heat exchanger for summer cooling, Energy and Buildings, 42(5), 645-648. DOI: 10.1016/j.enbuild.2009.11.001.

Goswami D.Y., 1993, Use of Underground Air Tunnels for Heating and Cooling Agricultural and Residential Buildings, Florida Cooperative Extension Service, 1-3.

Harris D.J., Helwig N., 2007, Solar chimney and building ventilation, Applied Energy, 84(2), 135-146. DOI: 10.1016/j.apenergy.2006.07.001

Kato S., Murakami S., Takahashi T., Gyobu T., 1997, Chained analysis of wind tunnel test and CFD on cross ventilation of large-scale market building, Journal of Wind Engineering & Industrial Aerodynamics, s67-68(97), 573-587. DOI: 10.1016/S0167-6105(97)00101-3.

Krarti M., Kreider J.F.1996, Analytical model for heat transfer in an underground air tunnel, Energy Conversion & Management, 37(10), 1561-1574. DOI: 10.1016/0196-8904(95)00208-1.

Maerefat M., Haghighi A.P., 2010, Passive cooling of buildings by using integrated earth to air heat exchanger and solar chimney, Renewable Energy, 35(10), 2316-2324. DOI: 10.1016/j.renene.2010.03.003.

Mathur J., Mathur S., Anupma. 2006, Summer-performance of inclined roof solar chimney for natural ventilation, Energy & Buildings, 38(10), 1156-1163. DOI: 10.1016/j.enbuild.2006.01.006

Mendes N., Winkelmann F.C., Lamberts R., Philippi P.C., 2003, Moisture effects on conduction loads, Energy and Buildings, 35 (7), 631-644. DOI: 10.1016/S0378-7788(02)00171-8.

Yıldız A., Ozgener O., Ozgener L., 2012, Energetic performance analysis of a solar photovoltaic cell (PV) assisted closed loop earth-to-air heat exchanger for solar greenhouse cooling: An experimental study for low energy architecture in Aegean Region, Renewable Energy, 44(4), 281-287. DOI: 10.1016/j.renene.2012.01.091.