Simulation and Analysis of Building Energy Consumption in Port passenger Stations

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ABSTRACT. Port passenger station buildings (PPSD) are an important part of transportation buildings in China, which is characterized by large human flow, long operating time, high load of equipment and lighting. The characteristics and functions of PPSD lead to the high energy consumption. However, the energy consumption analysis of PPSD was deficient. In this paper, the characteristics of energy consumption of port passenger stations in cold regions and hot summer and warm winter regions in China were analyzed. Based on eQUEST, the building models of port passenger stations are established. The influencing factors of the building energy consumption were analyzed through orthogonal experiment with SPSS. Results show that the factors such as summer indoor design temperature, heat source form, air conditioning form, window to wall ratio and lighting control mode are the key factors affecting the energy consumption of port passenger station.

1 Introduction

As an important part of public buildings, the traffic architecture has the characteristics of large space span, complex function, large passenger flow and long working time.[1,2,3] A large number of literatures at home and abroad have studied the energy consumption and energy saving potential of transportation hub buildings.

Song et al. [11] investigated the energy consumption of 36 railway stations in north China, and found that the average annual energy consumption per unit area of the high, medium and low grade railway stations was 423 kWh/m^2, 222 kwh/m^2 and 101 kwh/m^2. Huang et al. [12] studied the thermal comfort of the waiting room of a railway station in Harbin. Balaras et al. [13] investigated the energy consumption of 29 airport terminal buildings in three climatic zones in Greece, and obtained that the annual energy consumption per unit area of each climatic zone was 376.0kWh/(m2·a), 244.6kWh/(m2·a) and 168.3kWh/(m2·a). Perdamaian et al. [14] use building energy consumption simulation software to analyze Jakarta international airport terminal 3 building annual energy consumption and CO2 emissions.

There are few studies to analyze energy consumption of port passenger station. Existing studies mainly focus on energy consumption of cargo ports. Wu Peisen [4] discussed the production monitoring method during the construction of the green port in Tianjin Port. Zhang Rongxiang [5] comprehensively analyzed the influencing factors of port energy consumption and constructed the influence factor system of port energy consumption respectively.

At present, there is a lack of research on the energy consumption of port passenger station buildings, and the energy structure and energy consumption of port passenger station buildings in China is still unclear.

In this paper, eight port stations were investigated and tested to obtain the basic information and energy consumption of the port stations. the building models of the port passenger stations are established to analyze the influence factors of the port passenger station through orthogonal experiment.

2 Energy Consumption Investigation

2.1 investigation result

In this paper, eight port passenger stations were investigated and tested to obtain the basic information and energy consumption of the port passenger stations. There is basic information of the port station recorded in Tab.1. S1~S5 are 5 port passenger stations in cold regions and S6~S8 are 3 port passenger stations in hot summer and warm winter regions. Fig.1 shows the energy consumption of the port stations.

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 https://doi.org/10.1051/e3sconf/202127201011

Table1. Basic information of investigated ports

(a) Port stations in cold region

Port number	S1	S2	S3	S4	S5
Year of construction	2013	1995	2006	1995	2015
Building area (m2)	40000	7407.8	4200	2930.8	6902.2
Stories	4	5	4	2	2
Orientation	/	South and north	South and north	South and north	East and west
Daily business hours (h)	15	24	16	12	14
Annual passenger delivery volume ($\times 10^4$ people)	85.8	113.19	47.15	32.74	22.55
Cold source form	Water chiller	Split air conditioner	Ground source heat pump	Split air conditioner	Air-cooled water chiller
Heat source form	Municipal hot water	Split air conditioner	Ground source heat pump	Municipal hot water	Municipal hot water
Air conditioning form in the waiting hall	Fan Coil	Split air conditioner	Fan Coil	Split air conditioner	All air system
Air conditioning form in the offices	Fan Coil	Split air conditioner	Fan Coil	Split air conditioner	Fan Coil
Heating form in the waiting hall	Fan Coil	Split air conditioner	Fan Coil	Radiator	Radiator radiates floor heating
Heating form in the offices	Fan Coil	Split air conditioner	Fan Coil	Radiator	Radiator radiates floor heating

(b) Port stations in hot summer and warm winter region

Port number	S6	S7	S8
Year of construction	1994	2015	2008
Building area (m2)	5620	6440	5223.52
Stories	2	2	3
Orientation	South and north	South and north	South and north
Daily business hours (h)	24	24	24
Annual passenger delivery volume ($\times 10^4$ people)	293.47	251.52	290.24
Cold source form	Split air conditioner	Split air conditioner	Split air conditioner
Air conditioning form in the waiting hall	Split air conditioner	Split air conditioner	Split air conditioner
Air conditioning form in the offices	Split air conditioner	Split air conditioner	Split air conditioner

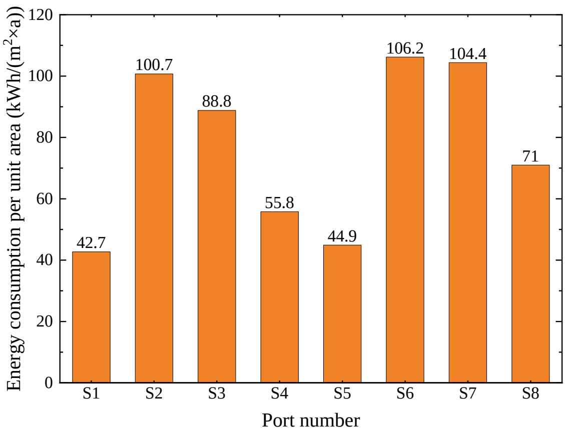


Figure 1. Energy consumption of port stations

As can be seen from Figure 1, there is a big difference in annual comprehensive energy consumption per unit area of port passenger station buildings in cold regions. Among them, S1 and S5 passenger stations use municipal hot water for heating and they are completed later and have better insulation performance of envelope structure, so the annual comprehensive energy consumption per unit area is relatively low. S4 passenger station also uses municipal hot water for heating in winter, but its completion time is earlier, and the insulation performance of the enclosure structure is poor, so the annual comprehensive energy consumption per unit area is higher than S1 and S5, while S2 and S3 passenger stations all use electricity for heating, so the comprehensive energy consumption is much higher than S1, S4 and S5.

Compared with the cold region, the difference of annual energy consumption per unit area of port passenger station building in hot summer and warm winter is relatively small. S8 passenger station has the lowest annual comprehensive energy consumption per unit area, which is due to the later completion time, good insulation performance of the envelope structure, and the use of energy-saving lamps, so the lighting energy consumption is low.

The comprehensive energy consumption per unit area of port passenger stations in cold regions ranges in 42.70~153.26kWh/(m^2·a), with an average of 81.02kWh/(m2·a). The comprehensive energy consumption per unit area of port passenger stations in hot summer and warm winter regions ranges in 71.05~106.19kWh/(m^2·a), with an average of 93.86kWh/(m2·a).

2.2 Thermal environment and comfort test

In this paper, the Port S2 and S7 are selected for the thermal comfort survey. Results of thermal environment data of the waiting hall are shown in Tab. 1 and Tab. 2.

Table2. Thermal environment test

(a) Port S2

	Indoor air parameters				Outdoor air parameters	
	Temperature (℃)	Relative humidity (%)	Radiation temperature (℃)	air velocity (m/s)	Temperature (℃)	Relative humidity (%)
Maximum	27.17	62.15	29.51	0.15	37.49	86.44
Minimum	25.74	55.49	25.71	0.01	27.47	58.02
Average	26.32	58.22	27.22	0.05	33.63	71.53

(b) Port S7

	Indoor air parameters				Outdoor air parameters	
	Temperature (℃)	Relative humidity (%)	Radiation temperature (℃)	air velocity (m/s)	Temperature (℃)	Relative humidity (%)
Maximum	28.41	63.59	29.53	0.19	40.88	91.98
Minimum	25.89	52.35	27.29	0.01	30.96	60.51
Average	26.85	56.09	28.17	0.04	36.31	75.33

According to the thermal comfort survey results, the linear regression line between the average thermal sensation vote (MTS) of port passenger station and the operating temperature was obtained by fitting, as shown in Figure 2. The thermal neutral temperature in the waiting hall of S2 passenger station was 26.7℃, close to the average temperature of 26.32℃ in the test area, indicating that passengers were comfortable with the thermal sensation in the waiting hall. The thermal neutral temperature in the waiting hall of S7 passenger station was 27.5℃, 0.65℃ higher than the average temperature in the test area, indicating that the thermal sensation of passengers to the waiting hall was slightly warmer. The results were consistent with the thermal sensation voting results of passengers.

The thermal sensation voting values within -1~+1 were regarded as satisfaction with the thermal environment. The passenger satisfaction rate within each temperature range is calculated, and the quadratic equation regression is obtained, as shown in Fig.3. The thermal environment with 80% satisfaction rate is defined as comfort environment. The acceptable temperature ranges for passengers in the waiting hall of Port S2 and S7 are 25.6~27.9℃ and 26.8~28.8℃, respectively.

 https://doi.org/10.1051/e3sconf/202127201011

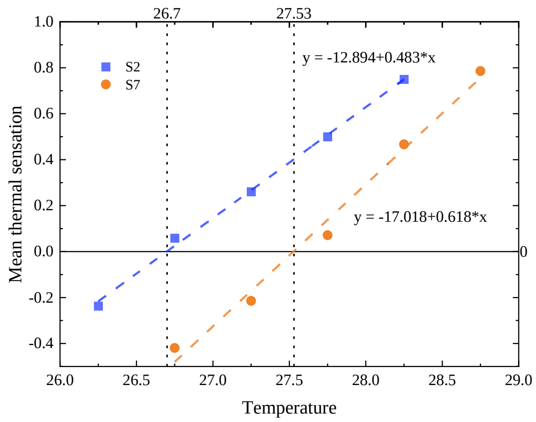


Figure 2. Mean thermal sensation

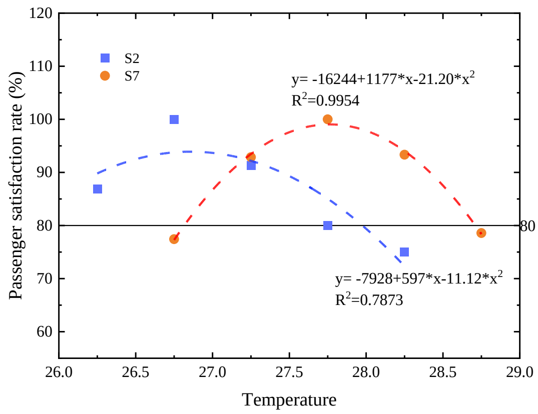


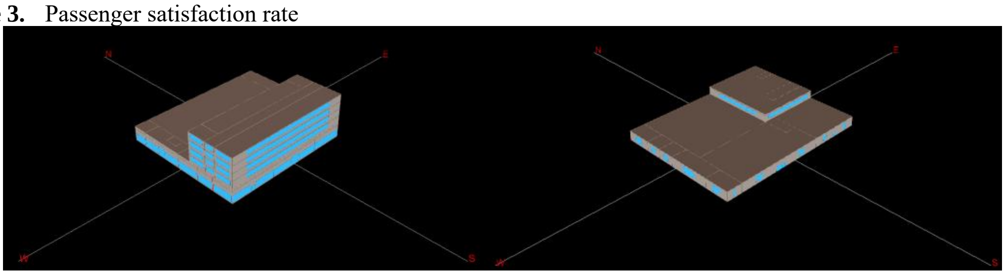
Figure 3. Passenger satisfaction rate

The temperature acceptance range of passengers in the waiting hall of port passenger stations is large, which is due to the adaptability and tolerance of passenger to the waiting thermal environment of ports. The actual temperature in the waiting hall of the two ports is lower than the thermal neutral temperature. The indoor temperature in the waiting hall can be improved appropriately to reduce the energy consumption of air conditioning.

3 Simulation

3.1 Building model

Using eQUEST, the building model of Port S2 in cold region and Port S7 in hot summer and warm winter region are established[6,7], as shown in Figure 4.



(a) Port S2 (b) Port S7

Figure 4. Building Models of S2 and S7

The building model of S2 passenger station has 5 floors above ground, with a north-south orientation, a building size coefficient of 0.196, and a total area of 73,48 m^2. The building model of S7 passenger station has 2 floors above the ground, with a north-south orientation, a building size coefficient of 0.19, and a total passenger station area of 6200m^2. The density of personnel is calculated by passenger transport volume, daily ship times and waiting hall area of passenger station. The lighting power density is selected according to the actual situation. The power density of equipment refers to the Public Building Energy Conservation Design Standard [8].

The heating period of S2 passenger station is from November 15 to March 15 of the next year, and the cooling period is from June 15 to September 30. Air conditioning system is used for heating and cooling. The air conditioning system adopts the separated type air conditioner. S7 passenger station operates all day. The cooling period of the building is set from April 15 to November 15, and there is no heating period. The air conditioning system also adopts the separated type air conditioner, and the interior design temperature is 26℃.

3.2 Results and validation of simulation

The simulation results show that the annual total energy consumption of S2 port passenger station model is 719,290kwh, among which heating and air conditioning energy consumption is the highest, accounting for 53% of the total energy consumption, electrical equipment energy consumption is the second, accounting for 35%, lighting system energy consumption is the lowest, but still accounting for 12%.The total annual energy consumption of S7 port passenger station is 6,886,70kwh, among which the energy consumption of air conditioning system is the highest, accounting for 37% of the total energy consumption. The energy consumption of electrical equipment and lighting system is similar, accounting for 30% and 33% of the total energy consumption respectively. The comparison between model results and actual survey data is shown in Tab. 3.

Table3. Simulation results and model verification

(a) Port S2

	Lighting	Equipment	Cooling	Heating	Total
Simulated result ($\times10^3$kWh)	85.70	250.51	95.49	287.58	719.28
Measured result ($\times10^3$kWh)	84.97	261.98	97.49	301.57	746.01
Relative error	0.86%	-4.38%	-2.05%	-4.64%	-3.58%

(b) Port S7

	Lighting	Equipment	Cooling	Total
Simulated result ($\times10^3$kWh)	227.57	205.07	256.03	688.67
Measured result ($\times10^3$kWh)	226.04	210.72	235.25	672.02
Relative error	0.68%	-2.68%	8.83%	-2.48%

The relative error of the total energy consumption is less than 5%, and the maximum relative error of each item of energy consumption is within 10%. which indicates that there is a good agreement between the simulated result and the actual energy consumption.

4 Orthogonal test method

4.1 Orthogonal test

Orthogonal test design is a kind of method of analyzing the multiple factors. According to the test factors, the number of levels and the interaction among the factors, the orthogonal table is designed. Relying on the orthogonality of orthogonal table, the typical experiment points are selected for experiments, which greatly reduces the number of experiments. The application of orthogonal test table design is a kind of efficient, fast and economic method of multifactor experimental design.

4.2 Design of orthogonal test

Table 4 list the influence factors and their horizontal values[8]. SPSS software is used to generate the orthogonal table and analyze the results of orthogonal test [9,10].

Table4. Influence factors and level values

(a) Port in cold region

Influence factors	Level 1	Level 2	Level 3
Roof heat transfer coefficient (W/(m^2·K))	0.35	0.45	0.55
Wall heat transfer coefficient (W/(m^2·K))	0.40	0.50	0.60
Window heat transfer coefficient (W/(m^2·K))	2.1	2.3	2.5
Window shading coefficient	0.36	0.40	0.43
Window wall ratio	0.4	0.5	0.6
Lighting power density (W/m^2)	5	6	7
Equipment power density (W/m^2)	8	10	12
Heating design temperature (℃)	18	20	22
Cooling design temperature (℃)	25	26	27
Frequency conversion control	Y	N	/

(b) Port in hot summer and warm winter region

Influence factors	Level 1	Level 2	Level 3
Roof heat transfer coefficient (W/(m^2·K))	0.3	0.4	0.5
Wall heat transfer coefficient (W/(m^2·K))	0.6	0.8	1
Window heat transfer coefficient (W/(m^2·K))	2	2.5	3
Window shading coefficient	0.6	0.7	0.8
Lighting power density (W/m^2)	5	6	7
Equipment power density (W/m^2)	8	10	12
Cooling design temperature (℃)	26	27	28
Frequency conversion control	Y	N	/

4.3 Results

The building model is used to simulate the building energy consumption of the port passenger station model under different parameters. SPSS software was used to analyze the results of the orthogonal test to determine the significance levels of each factor of total energy consumption of the buildings of the port passenger station. The results are shown in Tab.5.

Table5. Orthogonal experimental analysis of variance

S2		S7	
Influence factors	F	Influence factors	F
Roof heat transfer coefficient	58	Roof heat transfer coefficient	15
Wall heat transfer coefficient	12	Wall heat transfer coefficient	7
Window heat transfer coefficient	17	Window heat transfer coefficient	5
Window shading coefficient	1	Window shading coefficient	268
Window wall ratio	214	Lighting power density	4077
Lighting power density	76	Equipment power density	16534
Equipment power density	148	Cooling design temperature	7549
Frequency conversion control	538	Frequency conversion control	12487
Heating design temperature	1013		
Cooling design temperature	39		

According to the results of F test, the ranking of significance of the total energy consumption impact factors can be obtained:

Cold area: heating design temperature > frequency conversion control > window wall ratio > equipment power density > lighting power density > roof heat transfer coefficient > cooling design temperature > window heat transfer coefficient > wall heat transfer coefficient > window shading coefficient.

Hot summer and warm winter area: equipment power density > frequency conversion control > cooling design temperature > lighting power density > window shading coefficient > roof heat transfer coefficient > wall heat transfer coefficient > window heat transfer coefficient.

5 Conclusion

（1）The investigation shows that the port passenger station buildings have the characteristics of long operation time, large fluctuation of energy consumption and high building energy consumption. The average comprehensive energy consumption per unit area of investigated port passenger stations in cold regions and hot summer and warm winter regions are 81.02kWh/(m^2·a) and 93.86kWh/(m2·a), respectively.

（2）The result of thermal comfort test indicates that appropriately lowering indoor temperature can reduce the energy consumption of air conditioning and buildings.

（3）By analyzing the results of orthogonal experiment, the ranking of factors of building energy consumption is obtained, which can provide ideas for energy saving of port buildings.

Acknowledgement：

This work was supported by National Key R&D Program of China (grant number 2018YFC0705000)

Reference

1. Huang Haijun. Analysis of the main characteristics of traffic buildings in China[J]. Architectural Engineering Technology and Design, 2016，(16)：

https://doi.org/10.1051/e3sconf/202127201011

1175. (in Chinese)

2. Wei Qingfan, Wang Xin, Xiao He, et al. Current situation and features of energy consumption of Chinese public buildings[J]. Controduction Science and Technology, 2009，(08)：38-43. (in Chinese)
3. Zhang Yijun. About humanized design for airport terminal: taking Hongqiao transportation hub T2 terminal as example[j]. Architectural Journal, 2010，(11)：101-105．(in Chinese)
4. Wu Peisen, Kang Zhongfei. Review of energy consumption monitoring of a container terminal in Tianjin Port[J]. Journal of Green Science and Technology, 2018,12:183-189. (in Chinese)
5. Zhang Rongxiang. Construction of influencing factor system of port energy consumption[J]. Journal of Green Science and Technology, 2017,4:111-112. (in Chinese)
6. Ma Xiaoyun. Building energy consumption simulation software eQUEST and its application[J]. Building Energy & Environment, 2009，8(6)：77-80．(in Chinese)
7. Wang Weihan. Analysis of energy saving measures of low-rise residential building based on eQUEST. Architecture Technology, 2018，49(12)：1300-1303.
8. Lu Zhiqiang. Research on the influencing factors of energy consumption for Tianjin residential buildings[D]. School of Environmental Science and Engineering，Tianjin University, 2012. (in Chinese)
9. Wang Donghua. Multivariate statistical analysis and SPSS application[M]. Shanghai: East China University of Science and Technology Press, 2018：83-84.
10. Xie Yanqun. Investigation and measurement of residential energy consumption in Changsha and statistical analysis of its influencing factors[D]. Hunan university, 2007. (in Chinese)
11. Ling Song, Ying Wang, Xiaofeng Li. Energy performance and environmental quality of typical railway passenger stations in northern China [J]. Indoor and built environment, 2018, 27(03): 296-307.
12. Meng Huang, Yujie Lin. Thermal comfort of railway station's waiting room in severe cold regions of China [J]. Energy Procedia, 2017,134:749-756.
13. C.A. Balaras, E. Dascalaki, A. Gaglia, K. Droutsa. Energy conservation potential, HVAC installations and operational issues in Hellenic airports [J]. Energy and Buildings, 2003,35:1105-1120.
14. Laksana Gema Perdamaian, Rachmawan Budiarto, Mohammad Kholid Ridwan. Scenarios to Reduce Electricity Consumption and CO2 Emission at Terminal 3 Soekarno-Hatta International Airport [J]. Procedia environment sciences, 2013, 17:576-585.