CASE STUDY—HOW COULD WE OPTIMIZE THE ENERGY-EFFICIENT DESIGN FOR AN EXTRA-LARGE RAILWAY STATION WITH A COMPREHENSIVE SIMULATION?

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ABSTRACT

As a famous large-scale transportation hub in China, the Nanjing South Railway Station (NSRS) is a huge building of 380,000 m^2 and 50 meters high, with complex vertical route organization and comprehensive function zones. Because of its large façade, skylight, and huge air infiltration, the NSRS has encountered many difficulties in terms of HVAC (heating, ventilation, and air-conditioning) design, especially in calculating the most accurate heating and cooling loads during air infiltration. In order to address these issues, DeST (Designer's Simulation Toolkit), a building energy simulation tool developed by Tsinghua University, was combined with other tools to simulate the NSRS's HVAC load for an entire year. It is hoped that the results of this study will be helpful for exploring more efficient design strategies using simulation in other similar large-scale transportation hubs.

INTRODUCTION

According to the "11th Five-Year Plan" developed by the Ministry of Railways in China, 150 billion RMB will be devoted to improve the passenger transportation system in China, in which 548 railway stations and several super transportation centers will be built or reconstructed. The Nanjing South Railway Station (NSRS) is one of 16 newly built super transportation hubs in China (the others include the Beijing South Railway Station, the New Wuhan Railway Station, the Shanghai South Railway Station, and the New Guangzhou Railway Station). They are also referred to as "non-interchange transfer stations" (He, 2009), meaning that passengers can access subways, buses, taxis, and other means of transportation directly within the railway station.

Usually, a station building contains several areas, including a passenger area (such as a waiting hall), a service area (such as ticket offices), a management area (such as a control center), an administrative area (such as offices), a business area (such as shops and cafes), and many thoroughfares (Zhu, 2010). In older stations, the railway platforms and other rooms are always separate from each other. However, in accordance with the concept of non-interchange transfers, the design of modern station buildings is quite different. In new transportation stations, all the areas of the station are organized within one very large building which contains three floors: the ground floor is for arrivals, the second floor is for departures, and the third floor consists of waiting areas and shops.

In order to meet both functional demands and aesthetic requirements, modern station buildings are usually designed with high and large spaces with few physical partitions between different areas. In addition, in order to guarantee adequate illumination and visibility, vitreous barriers and skylights are usually employed. Another characteristic of these stations is that they serve high-density crowds that fluctuate significantly. Due to the enormous number of people who use these stations, the entry and exit doors are always kept open, leading to a huge amount of air infiltration that greatly increases the air conditioning loads.

Based on these architectural features, the characteristics of the HVAC loads of these buildings can be summarized as follows:

1) The heat transfer of the building envelope load is usually small, but the solar heat gain, particularly from large skylights, is quite large, as is the corresponding energy demand for space cooling.

2) At peak times, the density of people using the station is very high, but throughout the day it fluctuates tremendously, so the HVAC energy demand also fluctuates a great deal.

3) On the third floor, large external doors separate the waiting hall from the railway platform. When boarding is announced and tickets are checked, the doors on both sides open simultaneously, and a huge amount of air infiltration enters the air-conditioned area, increasing the HVAC energy demand. However, a lack of reliable tools for predicting airflows limits the effectiveness of energy consumption analysis of these buildings.

4) These stations consume much more energy than common buildings. Some research suggests that buildings larger than 20,000 ㎡ with central HVAC systems consume 3-8 times more energy than common buildings without central HVAC systems (Zhu, 2010).

As a non-interchange transfer station, the Nanjing South Railway Station (NSRS) faces all of these issues. The NSRS is more than 380,000 ㎡ in total area spread over 3 floors: the ground floor serves as an arrival area, the second floor serves as a railway platform, and the third floor serves as a departure area. The subway and the station's mechanical rooms are located on an underground level (Fig. 1).

During the cooling season, centrifugal chillers provide 7-12°C chilled water, and during the heating season, 0.7Mpa steam generated from the Nanjing Thermal Power Plant provides hot water. The station utilizes a two-pipe water system, in which circulating pumps are set for either summer or winter. A secondary pump system provides chilled water in summer (the primary pump's flux is constant and the secondary pump's flux is variable), and a variable-flux primary pump system provides hot water in winter. In addition, the HVAC terminal utilizes a primary return air system; through the use of terminal devices such as diffusers, nozzle outlets, and air handle units, the cooling space is divided into several zones.

In order to calculate the most accurate heating and cooling loads, DeST (Designer's Simulation Toolkit), a building energy simulation tool developed by Tsinghua University, was combined with other tools to simulate the NSRS's HVAC load for an entire year.

Figure 1 Architectural drawing of the NSRS

BILDINIG SIMULATION

Simulation toolset

DeST (Designer's Simulation Toolkit), developed by Tsinghua University in the early 1980s, aims to benefit practical and research-based building simulation applications in China. DeST can be used to simulate and analyze both building energy consumption and HVAC (heating, ventilation, and air-conditioning) systems (Jiang & Yan, 2006).

ECOTECT is a comprehensive 3D environmental modelling software package developed for both architects and engineers (Marsh, 1996). It provides an efficient way to visualize and analyze a building's performance in many aspects in order to create an energy-efficient and sustainable design. This study relied on its function of analyzing the direct and diffuse solar heat gain to calculate the Sun-shading Coefficient (SC) of the NSRS.

CONTAM, developed by NIST (National Institute of Standards and Technology), is a multi-zone indoor air quality and ventilation analysis program designed to help determine building airflows and pressures, contaminant concentrations, and personal exposure (NIST, 2005). This study used its function of determining airflows and pressures to calculate the infiltration and room-to-room airflows and pressure, wind pressures on the exterior construction, and stack effects induced by the temperature difference between indoor and outdoor areas.

Description of the simulated building

Based on their actual shapes and sizes, the external walls, partitions, windows, and façades of the Nanjing South Railway Station (NSRS) were input into DeST to establish a model of the building, as shown in Fig. 2. The ground floor (departure area) is shown in Fig. 3 & Fig. 4, and the third floor (waiting area) is shown in Fig. 5 & Fig. 6.

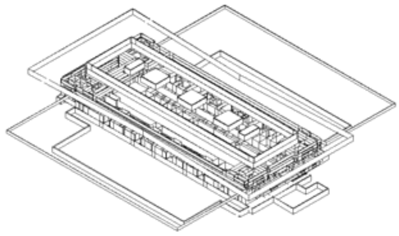


Fig 2 3D DeST model of the NSRS

Some simplifications were adopted in the model that did not appear to have any significant effects on our simulation results.

1) Time division:

The simulated year was divided into 3 parts: summer (May 1 to Sep. 30), winter (Dec. 1 to Feb. 28), and the transit season (spring and autumn). For summer, only the cooling load was calculated, and for winter, only the heating load was calculated. The transit season was considered as a non-air-conditioned period.

There are three reasons that cooling demand will seldom be present in the inner zones in winter, even on a very clear day with strong solar radiation:

Fisrtly, a total 200,000m³/h ouside air can handle part of the inner heat gain of waiting hall, and an average 650,000 m³/h non-organized infiltration overtun of the air conditioning air supply design partly (total air conditioning air supply is about 800,000 m³/h)

Secondly, the railway stations have a high requirement of space connectivity, so it is difficult to set physical partitions which result in a large amount of air infiltration between indoor and outdoor areas (Fig. 3 & Fig. 5), in the NSRS, the inner zone of the waiting hall temperature is set to 16°C, and the peripheral zone served as "transitional region" is set to 12°C.

Thirdly, with a two-pipe primary return air-conditioning system, the air between the inner and outer zones of the building mixes continusly.

Instead, in this project, the huge infiltration that lead to large heating demand and poor indoor thermal comfort is much more important than the cooling in the inner zones of the wating hall , which the designer concern most. From DeST's results, we also can learn that cooling demand is seldom be present in the inner zones in winter, even on a very clear day with strong solar radiation.(Fig.16)

2) Space simplification, including vertical and horizontal simplification:

Vertical simplification: because the building is very high and large, delaminated air-conditioning was considered. The waiting hall on the third floor, with a floor height of 37 meters, was divided horizontally into five layers: the bottom layer was 6 meters high, and the second layer from the bottom was 5.5 meters high (these two layers are used by passengers). The next three layers were 5.5, 10, and 10 meters high. According to experiments in other similar buildings, such as the Beijing South Railway Station, the Wuhan Railway Station, and the Shenzhen Railway station（Zhu, 2008）, the vertical temperature gradient in large spaces is about 0.3°C per meter. Therefore, the temperatures in the five layers from the bottom to the top in this simulation were set as 27°C, 28.8°C, 30.5°C, 32.8°C, and 35.8°C, respectively, with 27°C as the environmental control set point of the waiting hall.

Horizontal simplification: usually, railway stations have a high requirement of space connectivity, so it is difficult to set physical partitions which result in a large amount of air infiltration between indoor and outdoor areas (Fig. 3 & Fig. 5). However, in the DeST model, the waiting hall and the departure hall were divided into inner and peripheral zones with partitions, between which infiltration could exchange freely (Fig. 4 & Fig. 6).

Fig 3 Ground floor

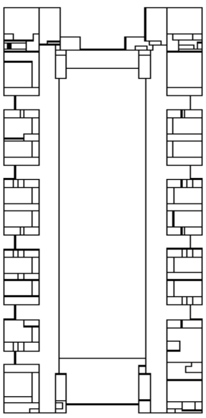


Fig 4 Ground floor model

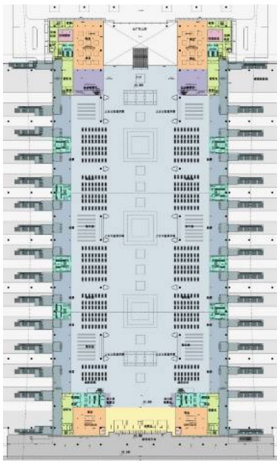


Fig 5 Third floor

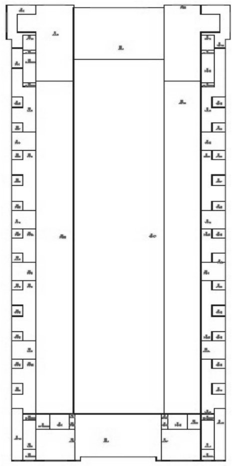


Fig 6 Third floor model

3) Shading simplification:

The shading that was considered in this study included the sheltered awning on the platform, the drop-off platform, and the overhanging roof. ECOTECT was used to obtain the SC (Sun-shading Coefficient), which was used as an input parameter in the DeST simulation.

4) Solar heat gain from the skylights:

Based on previous experience（Zhu, 2008）, it was calculated that 80% of the total solar heat gain would be absorbed by the air-conditioned region, and the remaining 20% would stay in the top three layers of the waiting hall without air-conditioning. This situation was reflected in the input parameter of solar heat gain in the DeST simulation.

5) Infiltration:

Usually, infiltration is not considered in building envelope optimization. However, for HVAC load simulations, it is quite necessary. The infiltration is driven by wind or stack pressure. In this study, CONTAM was used to calculate the hourly infiltration.

6) Space merging:

In the model construction, rooms with the same function were merged into one air-conditioning zone so as to expedite the simulation.

7) The underground floor:

The underground floor was not considered in the simulation.

Weather in Nanjing

Nanjing is a typical city in the "hot summer and cold winter" climate region in China, meaning that it has high temperatures and humidity in summer and low temperatures in winter. As a result, the simulation had to consider not only high cooling energy consumption in summer but also high heating energy consumption in winter. Table 1 shows the outdoor parameters for Nanjing. Fig. 7 shows the annual outdoor dry-bulb temperatures in Nanjing.

Table 1 Outdoor parameters for Nanjing

Summer outdoor dry-bulb temperature	34.8°C
Summer outdoor wet-bulb temperature	28.1°C
Winter outdoor dry-bulb temperature	-4°C
Winter outdoor relative humidity	79%
Average wind speed in summer	2.6m/s
Average wind speed in winter	2.6m/s

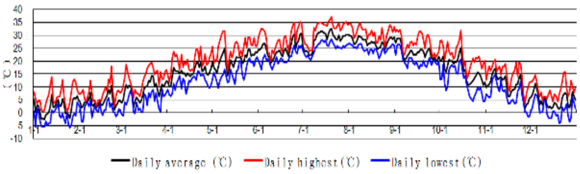


Fig. 7 Annual outdoor dry-bulb temperatures in Nanjing

Simulation input

The simulation input includes room function, people density, ouside air per person, and room heat gain. The parameters are shown in Table 2 (the data are based on the technical guidelines for railway station design in China (GB50226-2007)). Environmental control set points are shown in Table 3.

Table 3 Environmental control set point

	summer		winter	
	T °C	RH%	T °C	RH%
Waiting Hall	27	≤65	16	——
VIP room	25	≤65	20	——
Ticket office	26	≤65	20	——
Ticket Hall	27	≤65	16	——
Arrival Hall	28	≤65	12	——
office	26	≤65	18	——
Business	27	≤65	18	——
Restaurant	26	≤65	20	——
WC	——	——	12	——

RESULTS AND DISCUSSION

Sun-Shading

The NSRS has an overhanging roof that is about 21 meters long (shown in Fig. 8), which can be regarded as a perfect fixed external shading device. However, the SC (Sun-shading Coefficient) cannot be calculated by an experiential method. In this study, ECOTECT software was introduced to calculate the total solar radiation difference in order to estimate the shading effect and obtain the SC parameter as the input to the energy simulation software DeST. Fig. 9 shows the ECOTECT model.

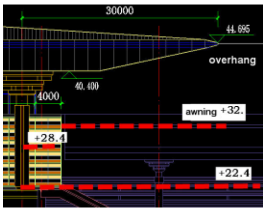


Figure 8: Sketch map of overhang

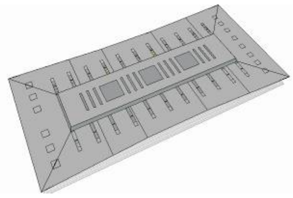


Figure 9: Ecotect model

Table 4 shows the solar radiation (both direct and diffuse radiation) of the façades with and without the overhang during the Summer Solstice. We can see that the overhanging roof effectively prevented the radiation from entering the building. The SC per month was also calculated (Fig. 10).

Usually, when solar radiation (both direct and diffuse) enters the room, part of it becomes convective and the other part becomes radiative due to a time lag. In this study, for simplicity, the SC of the overhanging roof did not take the time lag of the radiation into account; ECOTECT only calculated the radiation that arrived at the outdoor surface of the façade was calculated. The convective and radiative radiations that entered building were calculated by DeST.

Usually, dynamic whole building simulation can handle the shading effect, but in DeST, we find that it can handle the shading effect caused by direct radiation but can not handle the diffuse radiation. So, instead, we turn to Ecotect for help.

Fig. 11 shows the contrast of the SC with and without the overhang on different façades. It appears that the overhang on the building reduced the required energy load by 3.5%-9.8%.

Table 4 Solar radiant heat gain and SC

Summer Solstice	With overhang Wh/m^2	Without overhang Wh/m^2	SC
South	548.46	5712.82	9.60%
West	632.9	5178.85	12.22%
East	544.18	5306.89	10.25%
north	607.37	4190.32	14.49%

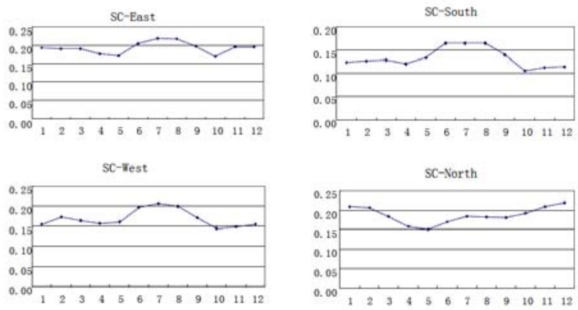


Fig. 10 SC of the overhang per month

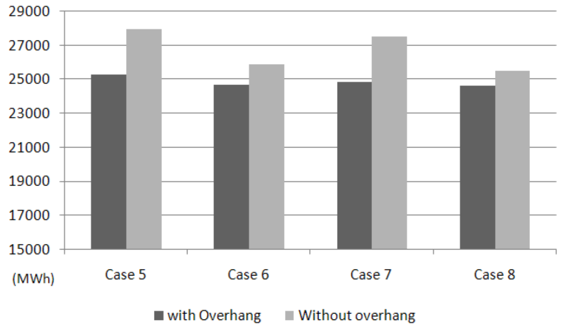


Fig. 11 Building energy demand difference

Building envelope optimization

The building envelope optimization is shown in Table 5. Four aspects of the building envelope optimization were examined: the external wall, the roof, the façades, and the skylight. The reference building was obtained from the "Public Buildings Energy-efficient Design Standards" code in China.

From the simulation results shown in Fig. 12, it appears that:

1) The thermal insulation of the external wall and roof had little effect on energy savings.

2) The biggest potential for energy savings was from the building façade. When considering the overhanging roof, as well as the requirement of natural lighting, the best choice for the façade was the low-e façade with low heat transmission coefficient, low sun-shading coefficient, and high visible light transmittance.

3) The skylight did not provide any shade, so the Low-E façade with low SC should take priority.

4) Overall, with the help of the simulation model, Case 1 (external wall), Case 3 (roof), Case 5 (façade), and Case 12 (skylight) were selected for the building envelope design to reduce the energy consumption of the building.

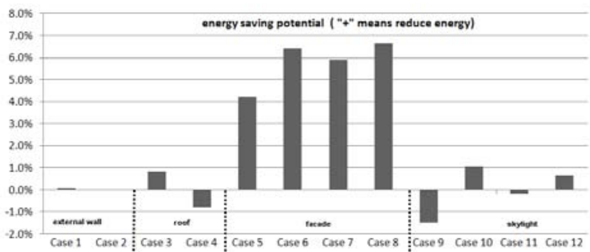


Fig. 12 Energy saving for envelope optimization

Building infiltration simulation

Methodology

Building infiltration simulation is the most important and the most difficult issue in this study. Building infiltration is always caused by the wind and stack pressure, and it is related to the outdoor wind speed, wind direction, and temperature difference. However, most building energy consumption simulation programs cannot effectively predict the infiltration in the kind of building examined in this study, either because they lack an airflow calculation module or because they cannot simulate very large rooms. In previous research, the air exchange volume between a building's interior and exterior areas or between a building's different rooms has been determined based on experience rather than on actual calculations. For example, although a ventilation calculation program, COMIS, was used in DOE-2 and EnergyPlus, this ventilation model was not actually coupled with a thermal model, thus decreasing its accuracy and reliability (Sahlin, 2003). In this study, a new methodology was developed to address this problem, which consisted of the following operation methods:

1) The CFD simulation program PHOENICS was used to calculate the wind pressure coefficients of complex buildings in 16 wind directions, especially for openings.

2) The multi-zone simulation program CONTAM was used to input the wind pressure coefficients to the building model and to obtain the quantitative values of the building infiltration under different conditions of outdoor temperature, wind speed, and wind direction.

3) Based on this data analysis, several practical formulas were developed to calculate the infiltration of the NSRS. The formulas were regressed as $F_i = f_i(v,t)$, where i is wind direction, v is wind speed, and t is outdoor temperature.

4) The simulation was conducted with segmented functions. In this study, the data resulted from evaluating more than 2000 cases and their corresponding calculations.

5) Outdoor temperature, wind speed, and wind direction were determined with the help of DeST's database. The data were then plugged into the formula to calculate the building infiltration, which was used as an input for the DeST program to simulate the annual building energy demand.

CFD and Multi-zone model simulation

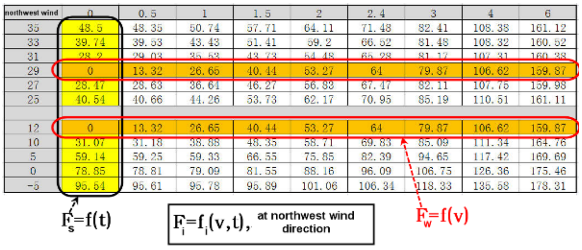
CFD was used to calculate the Wind Pressure Coefficients (WPC). CONTAM was used to establish the multi-zone model for the station. As the waiting hall on the third floor and the arrival hall on the ground floor are relatively independent, two models were established to examine them separately. In CONTAM, the basic formula is $Q = C_d(\Delta P)^n$, where Q is air volume, C_d is the resistance coefficient, and ΔP is the pressure difference. The resistance coefficients are shown in Table 6.

Table 6 Resistance coefficient used in the paper

Type	resistance coefficient (Cd)	Power (n)
outdoor	0.6	0.5
gate	0.78	0.5
stair	The experimental data in CONTAM from Achakji & Tamura, 1998 was used.	0.5

Result datafit

Taking the arrival area on the ground floor as an example, the wind outdoors is from the northwest and its speed is 2 m/s. The outdoor temperature is 35°C and the temperature in the arriving hall is 29°C. The total infiltration is 641,100 m^3/h. In a similar way, more than 2000 different results for wind, direction, and temperature were calculated (Fig. 13).



northwest wind	0	0.5	1	1.5	2	2.4	3	4	6
35	48.5	48.35	50.74	57.71	64.11	71.48	82.41	108.38	161.12
33	39.74	39.53	43.43	51.41	59.2	66.52	81.48	108.32	160.52
31	28.2	29.03	35.53	43.73	54.48	65.28	81.17	107.31	160.38
29	0	13.32	26.65	40.44	53.27	64	79.87	106.62	159.87
27	28.47	28.63	36.64	46.27	56.83	67.47	82.11	107.75	159.98
25	40.54	40.66	44.26	53.73	62.17	70.95	85.19	110.51	161.11
12	0	13.32	26.65	40.44	53.27	64	79.87	106.62	159.87
10	31.07	31.18	38.88	48.35	58.71	69.83	85.09	111.34	164.76
5	59.14	59.25	59.33	66.55	75.85	82.39	94.65	117.42	169.69
0	78.85	78.81	79.09	81.55	88.16	96.09	106.75	126.36	175.46
-5	95.54	95.61	95.78	95.89	101.06	106.34	118.33	135.58	178.31

Fig.13 Infiltration simulation results

If wind speed is 0 m/s, the infiltration is caused only by the stack effect, and it can be written as $F_1 = f_1(T_{out} - T_{in})$, where $f_1 \propto \sqrt{abs(T_{out} - T_{in})}$ and F_1 is the amount of infiltration. Also, there is no temperature difference between the interior and exterior. Therefore, the infiltration is caused only by wind pressure, which can be written as $F_2 = f_2(v)$, where $f_2 \propto v$ and v is wind speed.

Combine formulas F_1 and F_2 to get the total infiltration, which can be expressed as $F=aF_1+bF_2+c$, where a, b, and c are fitting coefficients and their numerical values have physical meanings.

The formula $F=aF_1+bF_2+c$ represents that the infiltration is caused by both wind and stack pressure. In this formula, if $a > b$, the stack effect is the major factor, and if $a < b$, the wind pressure is the major factor. If $a = b$, the wind pressure and the stack effect have a matched efficiency.

By fitting more than 2000 case results, many piecewise functions in different conditions were determined. For example, Table 7 shows the fitting formula for the arrival hall on the ground floor in winter. Fig. 14 shows the annual infiltration for the arriving hall.

Table7 Piecewise formula for the arrival hall on the ground floor in winter

Wind speed	Formula
0~1	$Q = 0.8350 \times \left[22.82 \times \sqrt{Abs(T_{out} - T_{in})}\right] + 0.2620 \times [32.986 \times v + 0.665] + 8.4020$
1~3	$Q = 0.3560 \times \left[22.82 \times \sqrt{Abs(T_{out} - T_{in})}\right] + 0.6230 \times [32.986 \times v + 0.665] + 19.6660$
3~6	$Q = 0.0320 \times \left[22.82 \times \sqrt{Abs(T_{out} - T_{in})}\right] + 0.9900 \times [32.986 \times v + 0.665] + 1.9330$

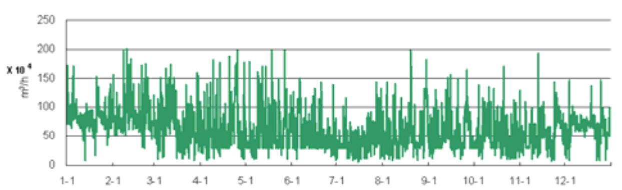


Fig. 14 Annual infiltration

Building energy demand Simulation results

According to the envelope optimization and infiltration, the annual HVAC load and other indicators were simulated, as shown in Table 8 and Fig. 15.

Table 8 Building energy demand simulation result

Building energy demand	Unit	Value
Maximum heat load	kW	15275.24
Maximum cooling load	kW	27582.30
Building energy demand for space heating	MWh	10343.3
Building energy demand for space cooling	MWh	32010.5
Building energy demand per unit area		
Maximum heating load	W/m^2	101.43
Maximum cooling load	W/ m^2	183.15
Building energy demand for space heating	kWh/ m^2	68.68
Building energy demand for space cooling	kWh/ m^2	212.55

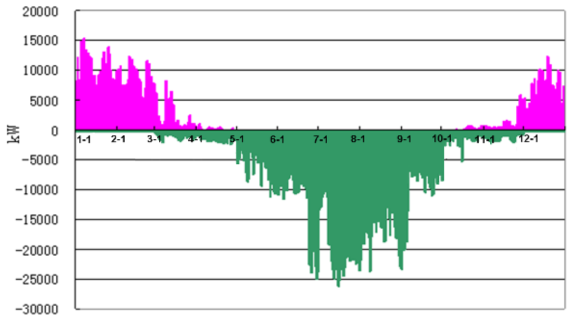


Fig. 15 Hourly building energy demand

From the simulation, the maximum heating/cooling load was calculated, which could serve as a good reference for the HVAC design, especially for cooler capacity selections. In addition, the total building energy demand is also an indicator of the energy consumption of the building. From the comparison of the building's energy demand for space cooling and heating (Fig. 16), it is clear that the infiltration load occupies about 42% of the total energy demand, highlighting the importance of focusing on infiltration in order to design an efficient HVAC system in this building.

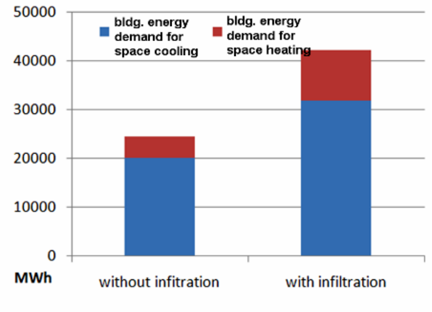


Fig. 16 Building energy demand comparison

Indoor thermal comfort

Finally, CFD simulation was introduced to predict indoor thermal comfort to guarantee a better indoor environment, as well as to influence the arrangement and optimize the performance of the HVAC terminals in the NSRS (Fig. 17).

There are many indicators for evaluating indoor thermal comfort, among which PMV (Predicted Mean Vote) and SET* (Standard Effective Temperature) are widely used. In this study, the interior environment was partly affected by solar radiation, so we adopted SET*, whose application is wider than PMV, as the indicator to evaluate and check the HVAC terminal design. The formula is written as follows:

$$\mathrm{SET}^* = 2.364 + 0.622\mathrm{Ta} + 6.63\varphi - 1.653V + 0.197 *$$
$$\left\{\left[0.95 * \sigma * (MRT_l + 273.15)^4 + 0.5q_s / 5.67 * 10^{-8}\right]^{0.25} - 273.15\right\}$$

where 20<Ta<40°C, 20%< φ <90%, 0.01< V <5 $\mathrm{m \cdot s^{-1}}$, 20< MRT_l <60°C, 50< q_s <1000 $\mathrm{W \cdot m^{-2}}$, and σ is the Stefan- Boltzmann constant. When SET* is between 20°C and 30°C, the indoor thermal comfort level is acceptable.

Taking the waiting hall on the third floor as an example, the final SET* distribution during the Summer Solstice is below 30°C, which demonstrates that the HVAC terminal design in the waiting hall is adequate in terms of thermal comfort.

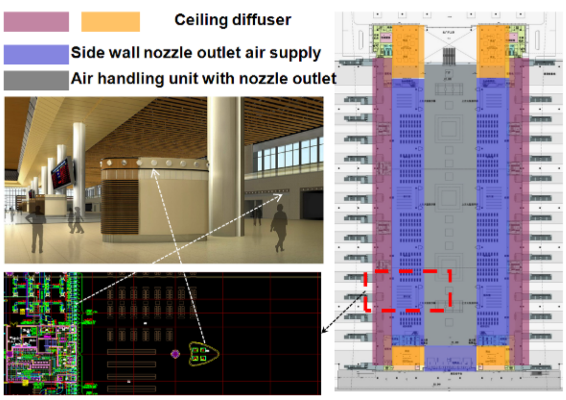


Fig. 17 Arrangement of terminal units

CONCLUSION

In this study, DeST was utilized in conjunction with other software in the HVAC design of the Nanjing South Railway Station (NSRS). This study attempted to explore a more effective design strategy for energy consumption simulation, and to provide some guidance for other buildings like the NSRS. The important steps and findings of this study are summarized as follows:

1) With the help of ECOTECT, the SC was determined, which was then used for envelope optimization and building energy demand simulation. In this step, it was found that envelope optimization was quite important for reducing energy consumption.

2) Building infiltration simulation, as the most important and difficult issue in this study, was examined with particular interest. A new methodology was established to address the specific requirements of buildings like the NSRS. Based on the simulation results, it was determined that the infiltration load was the most influential factor on the total building energy demand.

3) Finally, CFD simulation was conducted to predict indoor thermal comfort, which was then used to provide suggestions for the arrangement of the HVAC terminals.

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Table 2 Input of people density, ouside air and heat gain for the NSRS

Function	**People density (p/m^2)**	**Sensible load per person (W)**	**Humidity per person (kg/h)**	**Metabolic activity**	**Lighting density W/ m^2**	**Equip-ment density W/ m^2**	**Minimum outside air per person（m^3/h.p）**
Waiting Hall	0.67(summer) 0.18(winter)	51	0.102	Very-light work	10	5	Total 200,000 m^3/h
VIP room5	0.25	59.6	0.054	Seating	10	5	20
Ticket office	0.25	54.3	0.097	Very-light work	10	5	25
Ticket Hall	1.0(summer) 0.25(winter)	45.4	0.173	Light work	10	5	10
Entrance and Exit Hall	0.67(summer) 0.168(winter)	41.8	0.181	Light work	10	5	Total 180,000 m^3/h
office	0.25	54.3	0.97	Very-light work	11	20	30
Business	0.5	45.4	0.173	Light work	25	20	20
Restaurant	0.33	160.2	0.126	Light work	13	0	20
WC	0.1	45.4	0.173	Light work	5	0	—

Table 5 Envelope optimization settings

	External wall	**Roof**	**Façade**						**Skylight**	
			East, South and West			**North**				
	W/(m^2K)	W/(m^2 K)	W/(m^2 K)	Façade SC	Total SC	W/(m^2 K)	Façade SC	Total SC	W/(m^2 K)	Total SC
Reference Building	1.0	0.7	2.5	—	0.4	2.5	—	0.5	3.0	0.4
Case 1	0.8	—	—	—	—	—	—	—	—	—
Case 2	1.2	—	—	—	—	—	—	—	—	—
Case 3	—	0.5	—	—	—	—	—	—	—	—
Case 4	—	0.9	—	—	—	—	—	—	—	—
Case 5	—	—	2.97	0.83	0.158 0.108 0.141	2.97	0.83	0.158	—	—
Case 6	—	—	1.947	0.33	0.063 0.043 0.056	1.947	0.33	0.063	—	—
Case 7	—	—	1.98	0.69	0.131 0.090 0.117	1.98	0.69	0.131	—	—
Case 8	—	—	1.771	0.27	0.051 0.090 0.117	1.771	0.27	0.051	—	—
Case 9	—	—	—	—	—	—	—	—	2.97	0.83
Case 10	—	—	—	—	—	—	—	—	1.95	0.33
Case 11	—	—	—	—	—	—	—	—	1.98	0.69
Case 12	—	—	—	—	—	—	—	—	1.77	0.27