[*Technical Paper*]

Estimation Method of Cooling Load in an Underground Station

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ABSTRACT

This paper presents the estimation method of the cooling load in a platform of an underground station where various heat load factors exist, such as train wind, infiltration from upper floors, heat generation from the cooling system of cars, train brake systems, lighting and passengers on platforms. For appropriate load estimation, each factor is examined using results of measurement and Computational Fluid Dynamics (hereafter CFD). In the CFD simulation, trains are modeled as moving bodies to simulate train wind. The improved formula for each factor is proposed in this paper and the obtained cooling load shows good agreement with the real load.

1. Introduction

Underground stations on the Sobu Line of Japan Railway (hereafter JR Sobu Line) that links two big Japanese cities, that is Tokyo and Chiba, were constructed more than 30 years ago. The actual cooling load of the stations observed in recent years is much lower than the designed cooling load. The primary reason is the difference between the load property estimated 30 years ago and the recent actual one. For example, the heat release from the train brake system and cooling system of cars has decreased due to the improvement of train mechanics. In this paper, the real cooling load measured in Shin-nihombashi Station of JR Sobu Line is examined and the load estimation method is discussed in order to improve the accuracy of the estimated cooling load of underground stations.

2. Difference between designed load and real load

Fig. 1 compares the designed cooling load over 30 years ago and the recent real cooling load of Shin-nihombashi Station at a peak period in summer. In many underground stations on the JR Sobu Line, including Shin-nihombashi station, the actual cooling load is much lower than the designed cooling load. This is not only because there exists a difference in the number of trains and passengers, but also because the recent actual load property is different from the load property designed over 30 years ago, such as a reduction of heat release from trains and a decrease of the

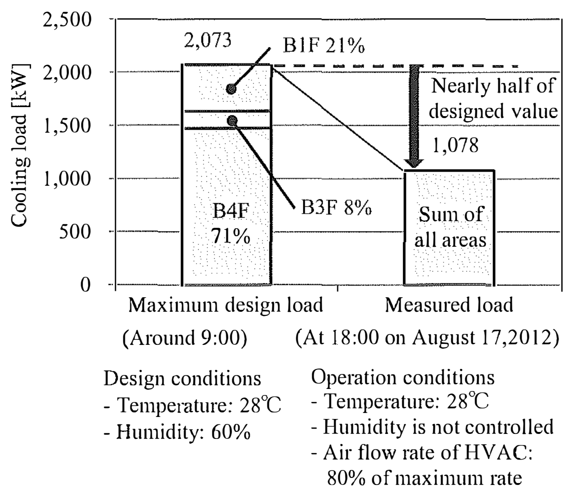

Fig. 1 Designed load over 30 years ago and the measured load at a peak period in summer 2012 for the platform of Shin-nihombashi Station

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tunnel temperature due to the improvement of the cooling systems of cars and brake systems. The purpose of this paper is to obtain an accurate estimation method of cooling load in the platforms of an underground station. The cooling load depends on several factors such as train wind, heat release from trains and infiltration from upper floors. Especially, the airflow rate of train wind should be estimated properly according to the shape of the station and the train schedule.

Equation (1) represents components that consist of the cooling load of underground stations.

$$q = q_W + q_T + q_I + q_P + q_L + q_{OA} + q_C \qquad (1)$$

where q : total load [W], q_W : train wind load [W], q_T : train heat release load including heat emitted from car cooling units [W], q_I : infiltration load [W], q_P : human body heat generation load [W], q_L : lighting load (including other equipment) [W], q_{OA} : outdoor air load for mechanical ventilation [W], q_C : heat load through walls [W]

The cooling load of underground stations on the JR Sobu Line was calculated by an original method of JR East Company based on the SHASE handbook (1981)[5]. Four load components, i.e., q_W , q_T , q_I and q_P are especially important and difficult to estimate; therefore, this paper focuses on them.

3. Estimation method of designed load

The conventional calculation methods of each component are shown below. The train wind load q_W caused by moving trains is calculated by equations (2) and (3).

$$q_{W.S} = 0.33 \cdot Q_T \left(t_r - t_p\right) \cdot N \cdot k_W \qquad (2)$$

$$q_{W.L} = 837 \cdot Q_T \left(x_r - x_p\right) \cdot N \cdot k_W \qquad (3)$$

$$q_T = (q_B + q_{AC}) \cdot \tau / 3600 \cdot N \cdot k_T \qquad (4)$$

where $q_{W.S}$: sensible heat load part of q_W [W], $q_{W.L}$: latent heat load part of q_W [W], Q_T : airflow rate of train wind [m^3/train], N : number of trains passing through station [trains/h], t_r, t_p : temperatures in tunnel and platform area [°C], x_r, x_p : humidity ratios in tunnel and platform area [kg/kg (DA)], k_W : influence coefficient of train wind on platform (0 to 1) [-], q_B : brake load [W], q_{AC} : heat from cooling unit of cars [W], τ : stopping time at the station [s], k_T : influence coefficient of train heat on platform (0 to 1) [-]

The designed value of Q_T in Shin-nihombashi Station was 3,000 m^3/train because the value of Q_T for a long, high-speed train is described as 2,500 to 4,500 m^3/train in transactions of the SHASE (1981)[6]. The temperature in the tunnel around 30 years ago was supposed to be 35°C because the tunnel was hot due to heat generation from trains. The humidity ratio in the tunnel was supposed to be the same humidity as the outside air. The influence coefficient of train wind on platform k_w was adopted as 0.5 at the design stage.

The train heat release load q_T was calculated in consideration of the brake heat and cooling load of cars as shown in equation (4). The influence coefficient of train heat on platform k_T was supposed to be 0.5, the same as k_w . In the calculation for Shin-nihombashi Station, infiltration load q_L was neglected. The human body heat generation load q_P was calculated with the assumption that the number of platform floor passengers was approximately 30% of the number of train passengers and the number of concourse floor passengers was estimated with a human density (0.2 persons/m^2) and floor area. The sensible heat and latent heat emitted from a human body were 70 W/person and 194 W/person, respectively.

4. Improvement of estimation method

In this paper, the calculation equations of each component were examined with measured data, such as train wind, train heat release and air flow velocity in Shin-nihombashi Station on August 29 and 30, 2012. **Fig. 2** shows structure and CFD model of Shin-nihombashi Station and the front / the near tunnel. In summer, the platform temperature and ventilation rate is usually controlled to 28℃ and 80% of maximum flow rate, respectively, and the humidity is not controlled in the station.

4.1 Train wind load q_W

The airflow rate of train wind into platform Q_T was estimated as 18,000 to 23,000 [m^3/train] on the basis of the velocity measurement. The measured value of Q_T is six times larger than the desigend value. When the railway schedule is tighter, the total flow rate increases but the flow rate per one train decreases; therefore, Q_T can be represented as equation (5).

$$Q_T = (a \cdot N + b) \cdot A \quad (5)$$

where A : cross sectional area of tunnel [m^2], a , b: constant values

Fig. 3 shows the measured temperature and humidity ratio at the end of the platform in Shin-nihombashi Station. Periodical fluctuation of temperature and humidity ratio caused by entering trains and leaving trains was observed but the variation was relatively low. The measurement suggests that temperature and humidity ratio in the tunnel can be considered as constant; therefore, the average values of t_r 28.8°C and x_r 0.0167 [kg/kg(DA)] were adopted to estimate train wind load q_W .

In order to clarify the influence coefficient of train wind on platform k_W , CFD simulation was carried out under isothermal conditions and a train was treated as a moving body to reproduce the train wind.

In **Fig. 4**, the measured airflow velocity at the end of the platform is compared to the CFD result from the train entering time to the train leaving time. **Fig. 4** indicates that the CFD simulation with a moving body can reproduce the train wind. In order to examine k_W , the platform space was divided into nine blocks because the platform consists of the track zones and the platform zone, and each zone was divided longitudinally into three blocks according to the air conditioning zone. Then the airflow rate of the train wind between the blocks was calculated with the CFD results.

Fig. 5 shows the transfer flow ratio between blocks, which means the round number of the transfer flow rate divided by the total flow rate of train wind. In this paper, the platform space was treated as one area and k_W was adopted as the sum of the transfer ratio for three blocks, i.e., 1. 0 (= 0.6+0.2+0.2).

Table 1 shows the conditions for load calculation used for designing and measured

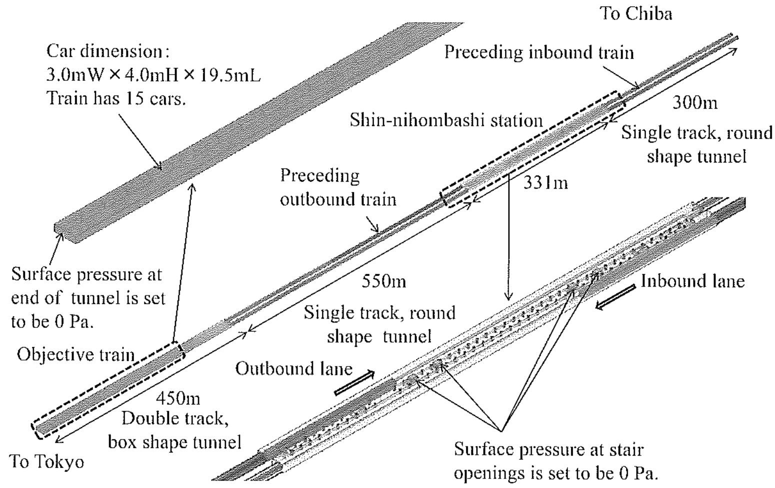

Fig. 2 Structure and CFD model of Shin-nihombashi Station and the front / the near tunnel

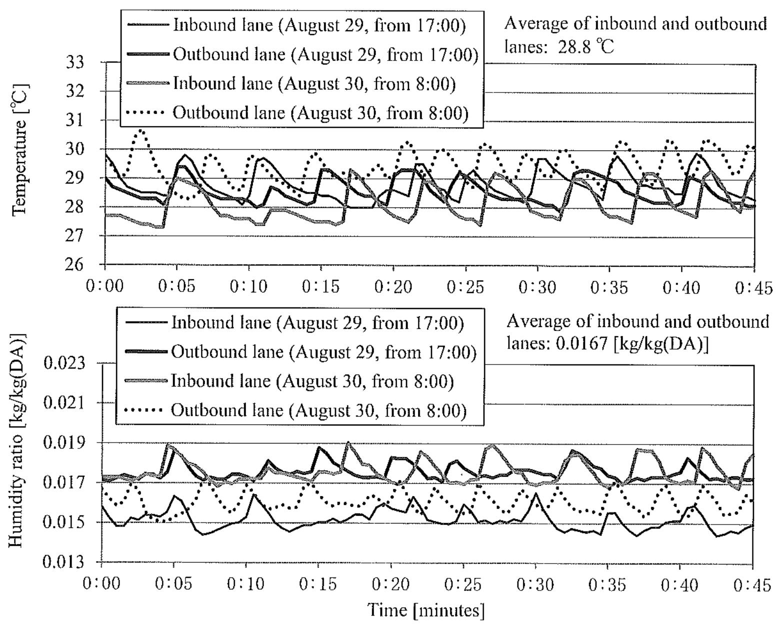

Fig. 3 Measured temperature and humidity ratio at the end of the platform

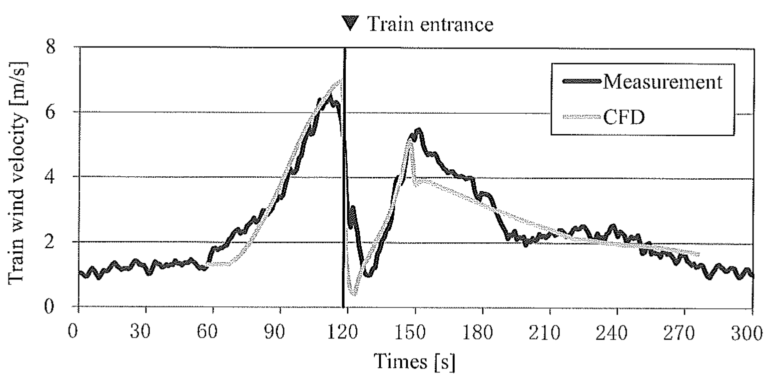

Fig. 4 Airflow velocities of measurement and CFD from the train entering time to the train leaving time at the end of the platform

value. **Fig. 6** compares q_W calculated by three methods. The first one is obtained with conditions used for designing shown in **Table 1** and Q_T is supposed to be 3,000 m^3/train; the second one is calculated with measured condition and Q_T is 3,000 m^3/train; and the last one is calculated with new equation (5) for Q_T and measured conditions. The value of Q_T calculated with equation (5) is larger than the conventional value with 3,000 m^3/train; however, q_W calculated by the new method is much smaller than the designed value calculated by the conventional equation because the actual enthalpy of air in the tunnel is much smaller than the design condition.

4.2 Train heat release load q_T

The temperature at the end of the platform rises for a few minutes just after the entrance of the train as shown in **fig. 2**. In order to study train heat release load q_T, the increased temperature of the platform from the entering to leaving of a train is integrated. The integrated value for 37 trains and the flow rate of the train wind obtained with equation (5) are multiplied to estimate the train heat release load q_T. The obtained value suggests that q_T can be estimated by equation (6). The appropriate value of k_T is considered to be 0.7 with the airflow distribution obtained by CFD simulation.

$$q_T = \sum_{0}^{N} c \cdot R \cdot k_T \qquad (6)$$

where c : coefficient (0.37 in this case), R : number of train cars [cars]

Fig. 7 compares train heat release load q_T calculated by equation (4) with the design condition in **Table 1** and the new equation (6) with the measured condition in **Table 1**. The equation (6) is much simpler than equation (4) but can estimate almost the same q_T as equation (4) with the same condition.

4.3 Infiltration load q_I

In an underground station, q_I highly correlates with the number of trains because the pressure in platform space becomes negative and then outside air enters from the entrances on the ground level when a train leaves the station. The wind velocity was measured at the openings, i.e., three entrances, accessway and two escalator openings connected to the ticket gate on the first basement of Shin-nihombashi

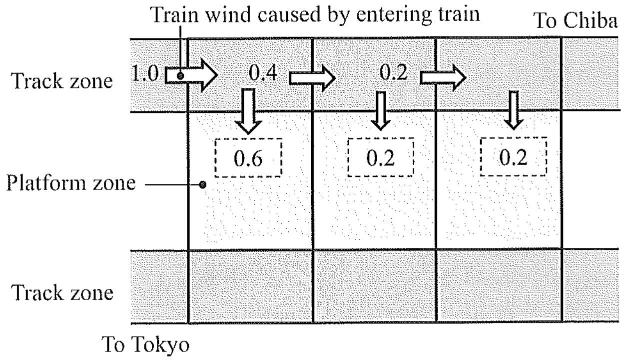

Fig. 5 Transfer flow ratio between blocks in the station

Table 1 Conditions used for load calculation

		Number of trains [trains/h]	Outside air temp [°C]	Outside air absolute humidity [kg/kg (DA)]	k_W	k_T
Conditions used for designing (30 years ago)	9	37	30.7	0.0185	0.5	0.5
	14	20	33.4	0.0186		
	16	22	32.4	0.0185		
	18	24	30.7	0.0187		
Measured value (Aug 17, 2012)	9	27	31.0	0.0187	1.0	0.7

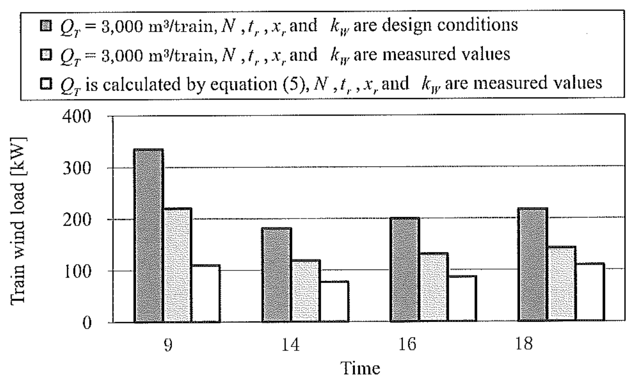

Fig. 6 Train wind loads calculated by conventional method and new one

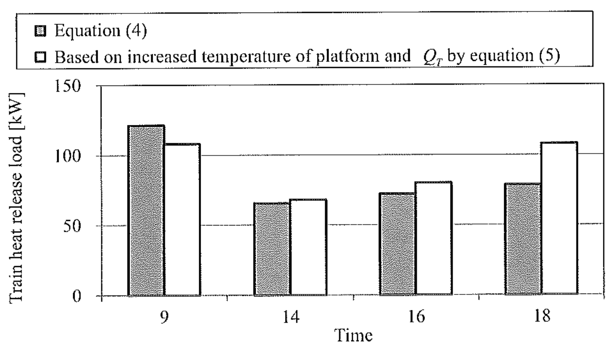

Fig. 7 Train heat release load calculated by conventional method and new one

Station. The result indicates the infiltration flow rate entering from the entrances on the ground level is about 3,300 m^3/h per train. However, a part of the entered air goes out again in the stairs area (7.6 mH) and the appropriate ratio of outside air that has a direct impact on q_I is considered to be approximately 50%.

4.4 Human body heat generation load q_P

In order to estimate actual human body heat generation load q_P, the data of the number of people entering and leaving this station obtained from the automatic ticket gates is used as the number of passengers, and the staying time of each floor is calculated from a walking speed of 0.7 m/s. According to the SHASE Handbook, the average waiting time of passengers on the platform floor is considered as half of the interval of the train schedule.

Fig. 8 shows the designed value of q_P and the estimated value with real conditions. The latter value is much smaller than the designed one because q_P was over-estimated at the design stage.

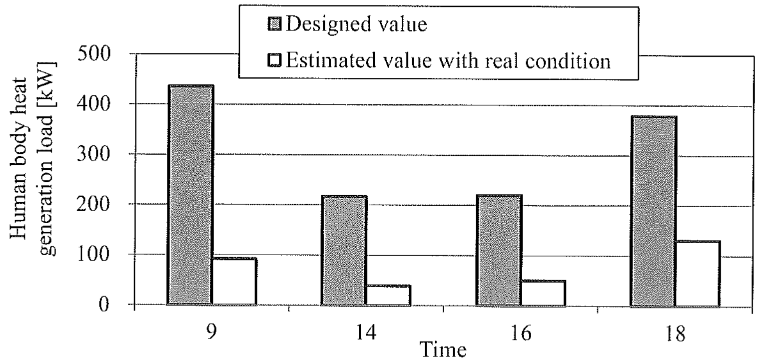

Fig. 8 Designed value around 30 years ago and estimated value with actual condition of human body heat generation load

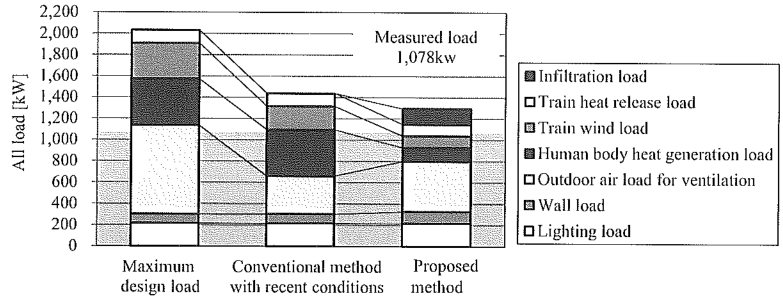

Fig. 9 Airflow velocities of measurement and CFD from the train entering time to the train leaving time at the end of the platform

5. Conclusions

Fig. 9 shows three maximum cooling loads, i.e., the designed value, the estimated value by the conventional method with recent conditions and the estimated value by the proposed method in this paper with recent conditions. The last one is closest to the real load of 1,078 kW.

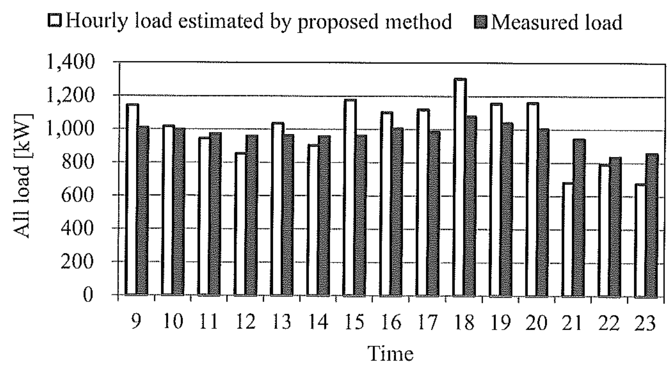

Fig. 10 Hourly load estimated by proposed method and measured load on August 17, 2012

Fig. 10 shows the hourly total cooling load q calculated by the proposed method and the measured load in Shin-nihombashi Station. Although some difference between them can be observed in figure 10, the proposed method can estimate appropriate total load q.

The proposed method in this paper is based on the measurement and CFD result for only one station, so we will conduct measurements and CFD simulations of underground stations to verify the validity of the proposed method.

要　約

建設後 30 年以上が経過したＪＲ総武線地下駅では，設計最大冷房負荷に対して実際の負荷が小さい傾向にある．これは車輌の高効率化による放熱量の減少など，設計時に想定した負荷性状と実際の負荷性状が異なることが一因である．そこで本報では，地下駅における設計最大冷房負荷の高精度推定を目的とし，新日本橋駅を対象とした設計条件の再検討，および現状の負荷推定を行った．

実測値と CFD 解析により算出した新日本橋駅の全負

荷は，空調負荷の構成要素を実態に合わせたことで，熱源の稼働実績値との差が 10%以内となった．構成要素毎で見ると，列車風負荷は設計時の負荷よりも小さい値となった．これは，ホーム階に流入する列車風が設計時の 6 倍以上と大きい反面，トンネル内空気の比エンタルピが設計条件よりも大幅に小さいためである．実測値から算出した列車放熱負荷は，設計時の負荷とほぼ同等であり，当駅の改札機入出者データにより算出した人体発熱負荷は大幅に小さい値となった．また、設計時に非考慮の隙間風負荷は，特に列車本数の多い朝夕において大きい値となった。

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