Study on Energy consumption calculation method of Fabricated building wall

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Abstract. The fabricated building wall is an important component of prefabricated building. Its specific form and processing mode have an important influence on the energy consumption of the whole industrial chain of prefabricated building. At present, there are few researches on the calculation of energy consumption data of fabricated building wall in China. Therefore, this paper mainly studies the calculation method of the energy consumption of fabricated building wall. The typical wall is selected as an example to calculate and obtain the specific energy consumption data. Paper mainly considers the production, transportation, construction and use of the four stages of energy consumption. The production stage is analyzed by field measurement. The use stage is analyzed by means of simulation calculation. The transportation and construction stage is calculated by empirical formula. This study can be used as a reference for research on energy consumption of prefabricated building in the future.

1. Introduction
China's building energy consumption accounts for about 27% of total energy consumption. Reducing building energy consumption is an important direction for energy conservation in our country [1]. At present, prefabricated building are developing rapidly. In order to reduce the energy consumption of the building, we need to accurately evaluate the energy consumption of prefabricated building. In the domestic research, there are many researches on the economic benefits of buildings, such as, the study on mechanical properties of wall and the selection of raw materials [2]. The research on environmental benefit includes taking wall material as research object, adopting fuzzy mathematics analytic hierarchy process method based on life cycle, building a wall material green degree evaluation model and evaluating the wall materials [3]. The relationship among wall composition, structure and performance is studied. The optimum proportion of wall material is obtained, which provides technical support for wall production process [4]. On the basis of assuming some calculated data, the carbon emission of the production process of wall material is calculated [5]. These studies only explain the energy saving and consumption reduction of buildings in a broad sense. They don not quantify the building energy consumption. This paper takes the wall of prefabricated building as an example to study the evaluation method of the energy consumption of prefabricated building in order to provide a reference for the evaluation.
2. Research method
This paper mainly analyzes the energy consumption in the production, transportation, construction and use of prefabricated building wall. The main research methods of each stage are as follows. The energy consumption in the production stage is mainly obtained by testing, the energy consumption in the transportation and construction phase is calculated by the existing empirical formula, and the energy consumption in the use phase is obtained by numerical simulation.

2.1. Measurement of Energy consumption in production stage

2.1.1. Definition of measurement range. The measurement range of the whole production process should be defined before the energy consumption is measured. According to the actual situation of the factory, we divide the measuring area into five parts: concrete production area, automatic production line area, field transportation area, stacking transportation area and Steel production area. The measuring area of concrete production area starts from concrete entering the mixing station until concrete mixing is completed. The scope of automatic production line area begins with concrete entering the distributor until the wall is produced and maintained. The scope of stacking transportation area is from the completion of wall maintenance to the transportation of the wall to the stacking yard. The scope of stacking transportation area only includes the process of wall lifting from the truck to the designated site of the stacking yard. The scope of Steel production area only considers the energy consumption generated when the steel bar is processed during the stable operation of the equipment.

2.1.2. Measuring method. Combined with the actual situation of the production site, we have formulated a 6-day measurement program.

Measuring parameters include current, voltage of equipment and the operation time (obtained by power recorder), daily consumption of production materials, daily concrete consumption, wall model and corresponding material mix table (Obtained through the production work log).

The measuring instrument includes 9 three-phase electricity recorders (DIK-200), a Hand-held clamp type recorder, a digital multipurpose meter (MS8238), 6 AC current transformer (300:5), 6 AC current transformer (200:5) and 15 AC current transformer (100:5).

2.1.3. Test data processing. The main types of energy consumption in the production stage of fabricated building wall are electricity. In addition to the maintenance process, other production equipment is driven by electric power. Because the quantity and specification of the wall produced by the factory are not uniform every day, the energy consumption of the wall is measured by the Unit cubic concrete consumes electricity.

The total power consumption in the production stage of wall is composed of five parts: concrete production, automatic production line, field transportation, stacking transportation and steel production. The formula is as follows:

\[ E_f = E_{f1} + E_{f2} + E_{f3} + E_{f4} + E_{f5} \] (1)

In the formula: \( E_f \) ——Total power consumption in wall production stage, (kw.h) / m³; \( E_{f1} \) ——Concrete production power consumption, (kw.h) / m³; \( E_{f2} \) ——Power consumption of automatic production line, (kw.h) / m³; \( E_{f3} \) ——Field transportation power consumption, (kw.h) / m³; \( E_{f4} \) ——Stacking transport power consumption, (kw.h) / m³; \( E_{f5} \) ——Power consumption of steel bar production, (kw.h) / m³.

The calculation of power consumption in each area in the production stage is based on the integration of the instantaneous working current, voltage and operating time of the equipment in operation, and then divided by the total amount of concrete used in the production. The formula is as follows:

\[ E_{fi} = \frac{\sqrt{3} \cos \varphi \sum U_j I_j}{3.6 \times 10^6 V} \] (2)
In the formula: $E_{fi}$——i-zone power consumption, (kw.h)/m³; $I_j$——j second current value of production equipment, A; $U_j$——j second voltage value of production equipment, V; $t$——Time interval, s; $V$——Concrete consumption, m³; $\cos \phi$——Power factor (Take 0.7~0.85).

Finally, the total power consumption of this stage will be converted into standard coal according to the energy ratio. The formula is as follows:

$$E_{SC} = \alpha E_f$$  \hspace{1cm} (3)

In the formula: $E_{SC}$——Total energy consumption expressed by standard coal, kgce; $E_f$——Total power consumption in wall production stage, (kw·h); $\alpha$——Electric transfer standard coal coefficient, take 0.424, kgce/(kw·h).

2.2. Calculation of Energy consumption in Transportation and Construction stage

The energy consumption of fabricated building wall in transportation and construction can be calculated by existing empirical formulas.

1) The energy consumption calculation formula of the wall transportation stage is shown in the following equation:

$$E_{YS} = k \sum_{i=1}^{n} D_i L_i \rho$$ \hspace{1cm} (4)

In the formula: $E_{YS}$——Total energy consumption in transportation stage, kgce; $D_i$——100 km fuel consumption of type i transport vehicles, kg/(t.km); $L_i$——Type i distance of transport, km; $\rho$——Wall density, kg/m³; $k$——Fuel transfer standard coal coefficient, kgce/kg.

2) The energy consumption calculation formula of the wall construction stage is shown in the following equation:

$$E_{SG} = \alpha \sum_{i=1}^{n} P_{Di} T_{Di} N_i$$ \hspace{1cm} (5)

In the formula: $E_{SG}$——Total power consumption of construction machines, kgce; $P_{Di}$——Electrical power of type i construction machine, kw; $T_{Di}$——Operating hours of type i construction machine, h; $N_i$——Machine-team of type i construction machines; $\alpha$——Electric transfer standard coal coefficient, take 0.424, kgce/(kw·h).

2.3 Simulation of Energy consumption in use stage

The main energy consumption of the wall in the use stage is the heat dissipation. The energy consumption of the wall at this stage can be obtained by establishing a one-dimensional steady-state heat conduction model and simulating the heat conduction process of the wall. The heat transfer of the wall will be affected by the formation of the heat bridge in the joint of the wall due to the different materials. The literature shows that the heat transfer coefficient of the structural heat bridge line cannot be completely eliminated by the general wall exterior insulation [6]. So the energy consumption of the wall thermal bridge should be considered in the calculation.

Through the simulation calculation, the temperature field distribution cloud map and the heat flow density value of the wall at different times can be obtained. The energy consumption of the wall at this stage can be calculated by equation 6.

$$E_{SY} = \xi Aqt$$ \hspace{1cm} (6)

In the formula: $E_{SY}$——Energy consumption in use stage expressed by Standard Coal, kgce; $A$——Heat-exchange surface, m²; $q$——heat flux, w/m²; $T$——Heat dissipation time, s; $\xi$——Thermal transfer standard coal coefficient, take $3.42 \times 10^{-5}$, kgce/kJ.
3. The result of calculation

According to the above method, the aerated concrete composite wall produced in the factory is taken as the typical case list. The energy consumption of the wall production, transportation, construction and use is calculated.

1) Production energy consumption

The measured and collected data are introduced into the formula 1, 2, 3. The energy consumption of the wall production stage is calculated and summarized in Table 1.

| automatic production line | Concrete production | stacking transportation | field transportation | Steel production | summation |
|---------------------------|---------------------|-------------------------|----------------------|-----------------|-----------|
| 3.37                      | 1.91                | 0.68                    | 0.30                 | 1.59            | 7.85      |

(Note: the data in the table are the energy consumption per cubic concrete)

2) Transport and construction energy consumption

Calculating the energy consumption of wall transportation: Transportation mode is highway transportation, fuel is diesel, transportation distance is 50km (transportation in the same province). The density of aerated concrete is 500kg/m³, the combined energy consumption of automobile freight (k×Di) is 0.0844kgce/（t.km） [7]. Taking the data into formula 4, the transport energy consumption of aerated concrete wall per unit volume is 2.11kgce.

Calculating the energy consumption of wall construction: According to basic quota of national unified construction engineering foundation, the per cubic aerated concrete wall construction need 0.00386 mortar mixer (200L), 0.0074 machine-team angle bender (Φ 40 mm) and 0.0074 machine-team cut-off machine (Φ 40 mm) [8]. The operation time of construction machines shall be calculated at 8h per day. The power of mortar mixer and cut-off machine shall be 2.5 kw, and that of angle bender shall be 3 kw. If the above data are put into equation 5, the energy consumption of unit volume wall construction is 0.17 kgce.

3) Energy in use

Beijing winter is taken as an example for heat transfer simulation. Outdoor-design temperature for heating is -9℃, indoor-design temperature is 18℃, the wall outer surface convection heat transfer coefficient is 23.3W/(m².K) and the wall interior surface convection heat transfer coefficient is 8.7 W/(m².K). Table 2 shows the thermal physical parameters of wall materials Figure 1 is wall heat conduction model diagram (heat exchange area 0.26m²).

| Wall materials | λ [w/(m.k)] | Cp [J/(kg.k)] | ρ [Kg/m³] |
|----------------|-------------|--------------|-----------|
| aerated concrete | 0.22 | 1150.8 | 700 |
| reinforced concrete | 1.74 | 920 | 2500 |
| EPS insulation board | 0.04 | 2414.8 | 18 |
The model was imported into fluent software for simulation calculation. The cloud map of wall temperature field distribution was obtained (see Figure 2). The influence of wall thermal bridge on the heat dissipation process could be seen directly. At the same time, the heat transfer quantity per unit time (Aq) of the wall is 11.79W. According to equation 6, daily wall heat dissipation per unit area (calculated at 8h) is 1305.97kJ, and converted into standard coal is 0.05kgce.

In summary, the total energy consumption value of aerated concrete walls per unit volume in the production, transportation and construction stages can be calculated as 10.13kgce, as shown in table 3. Since the energy consumption during the use period is related to the construction time, only one day's energy consumption is calculated in this paper, with a value of 0.05kgce.

Table 3. Energy consumption summary table (kgce)

| Production energy consumption | Transport energy consumption | Construction energy consumption | summation |
|-------------------------------|-----------------------------|-------------------------------|-----------|
| 7.85                          | 2.11                        | 0.17                          | 10.13     |

4. Summary
In this paper, the energy consumption of fabricated building walls is calculated scientifically and quantitatively by means of actual measurement, simulation and theoretical analysis. From the calculation results, we can see that the proportion of energy consumption in production stage is the most (excluding the use period). The total energy consumption of wall can be obviously reduced by reducing the proportion of energy consumption in production stage. The calculation method presented in this paper has strong operability and practical significance. It has certain reference value in studying the calculation of energy consumption.

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