International Conference on Applied Energy 2020
Dec. 1 - Dec. 10, 2020, Bangkok / Virtual
Paper ID: 487

Onsite Investigation of a Balance Correction Test Method Based On Double-sided Heat Flow Meter

Xing Shi[1], Guangcai Gong[1*], Yongchao Liu[1], Pei Peng[1]
College of Civil Engineering, Hunan University, Changsha, 410082, China

ABSTRACT

A balance correction test method(BCTM) based on a double-sided heat flow meter is proposed in this study, which is used to optimize the thermal performance testing method of the building envelope. The accuracy and applicability of this method are verified by using the measured data of typical buildings in China's hot summer and cold winter regions. The results show that: for walls in the steady state and unidirectional unsteady state heat transfer process, the balance correction test method can accurately obtain the thermal performance parameters of the wall, and the error is only 6.48%, 5.56% and 5.8%, and this method can effectively shorten the measurement time and calculation period.

Keywords: Balance correction test method; Double-side heat flow meter; Hot summer and cold winter; Thermal performance; Building envelope

1. INTRODUCTION

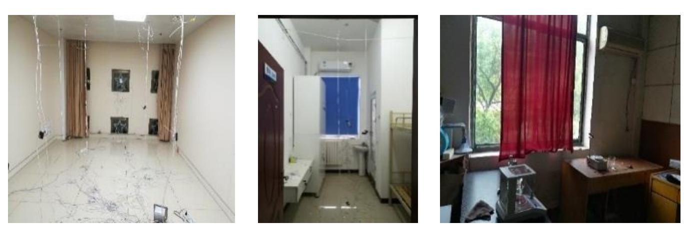
The heat flow meter method is a commonly used non-destructive standardized method for evaluating the heat transfer characteristics of walls. The main principle of this method is Fourier's law, at present, it is mainly used under winter heating conditions in cold areas.

The main factors affecting the heat flow meter method are: 1) the shape, size and pasting position of the heat flow meter[1][2]; 2) equipment accuracy[3]; 3) test wall orientation[4]; 4) weather and climate conditions (wind speed, solar radiation and precipitation)[5]; 5) temperature difference and heat flow[1] [6]; 6) heat flow direction[7]; 7) temperature fluctuation [8]; 8) experiment duration[9]; 9)data post-processing and analysis capabilities. Mihaela Teni and others evaluated the advantages and disadvantages, limitations and errors of various methods, and pointed out that the main issues that still need to be studied are: 1) the amount of field tests conducted in the summer environment is very small, so the season and geographical restrictions have not been overcome; 2) the current test period is long, and it is difficult to perform more measurements within a given time limit; 3) it is necessary to determine the optimal range of other influencing factors, which should take into account the measurement duration and data collection frequency [10].

Therefore, a balance correction test method based on the double-side heat flow meter is proposed in this research to optimize the current thermal performance detection and calculation methods of the building envelope. In addition, four types of working conditions of three typical buildings in China's hot summer and cold winter areas were measured to verify the accuracy and applicability of the method.

2. CASE INTERPRETATION

Tests were conducted on three buildings' outer wall, which are located in typical areas in hot summer and cold winter areas: Shaoshan, Ningxiang and Changsha, as shown in **Fig 1**. The specific structure, test environment and content of each external wall are shown in **Table 1**, refer to appendix.



(a) No.1 wall (b) No.2 wall (c) No.3 wall

Fig 1 Site map of test building and exterior wall

Selection and peer-review under responsibility of the scientific committee of the 12th Int. Conf. on Applied Energy (ICAE2020).

3. METHODOLOGY

Aiming at the problems of the traditional method, this chapter proposes a balance correction test method based on the double-sided heat flow meter.

The main idea of the balance correction test method is: When the heat flow through the inner and outer surfaces of the wall at a certain time is the same in size and direction, excluding the influence of the heat storage of the wall itself, the heat loss and diffusion in the direction parallel to the wall are less at this time, most of the heat will be steadily transferred from the indoor (outdoor) side to the outdoor (inside) side in a direction perpendicular to the wall, therefore, these points can be approximately regarded as the point closest to the "one-dimensional steady-state heat transfer" state, name the points: equilibrium heat flow point q_b and equilibrium temperature difference point T_b. Based on the above reasons, the equilibrium state is then used to correct the absolute value of the average heat flow and the temperature difference, so that the measured data at all times are close to the "one-dimensional steady-state heat transfer" process. And calculate the thermal resistance using the heat flow value q after the balance correction and the temperature difference value T, as shown in Eq(1)-Eq(2):

$$q=\frac{1}{2}\left(\frac{\sum_{i=1}^{n} q_b}{n}+q_a\right) \tag{1}$$

$$T=\frac{1}{2}\left(\frac{\sum_{i=1}^{n} T_b}{n}+T_a\right) \tag{2}$$

The formula for calculating the thermal resistance of the building envelope as Eq(3):

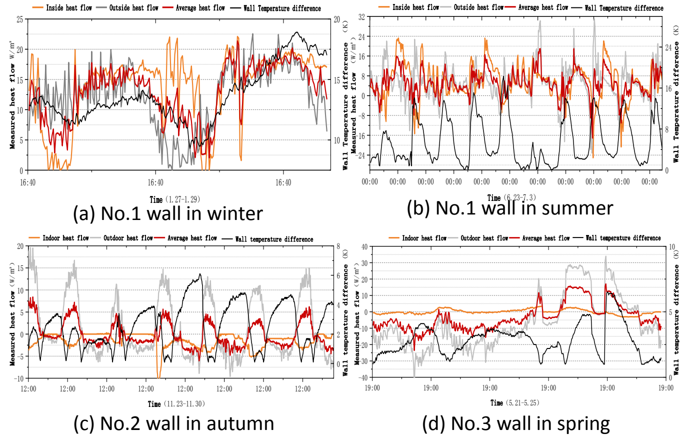
$$\overline{R}=\frac{\sum_{j=1}^{m}|T_j|}{\sum_{j=1}^{m}|q_j|} \tag{3}$$

In summary, the Eq(1)-(3) constitutes a balance correction method based on a double-sided heat flow meter.

4. RESULTS AND DISCUSSION

4.1 Test data analysis

The wall temperature difference, one-sided heat flow and average heat flow obtained from the four types of working conditions are shown in **Fig 2**:



(a) No.1 wall in winter (b) No.1 wall in summer

(c) No.2 wall in autumn (d) No.3 wall in spring

Fig 2 Thermal performance test data of four working conditions

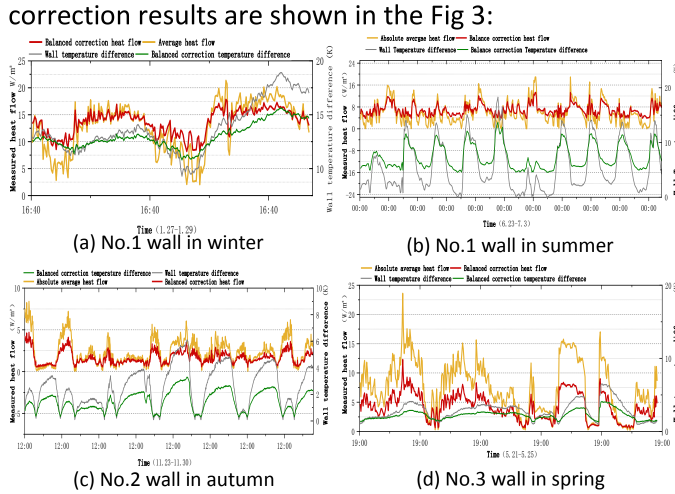
The universal laws about heat transfer of building envelope can be obtained:

(1) Compared with the unilateral heat flow curve, the average heat flow change law is more stable, which can effectively weaken the test peak value of the unilateral heat flow.

(2) In winter and summer, the change of average heat flow is mainly affected by indoor heat flow, so the influence of indoor heat flow on the heat transfer process dominates; in the transition season, on the contrary, the change of outdoor heat flow dominates.

4.2 Balance correction test method data analysis

Read the indoor and outdoor heat flow value, take the equilibrium heat flow point with same value and same transfer direction, use the Eq(1)-(2) to correct the absolute value of average heat flow and the temperature difference between indoor and outdoor walls. The correction results are shown in the Fig 3:

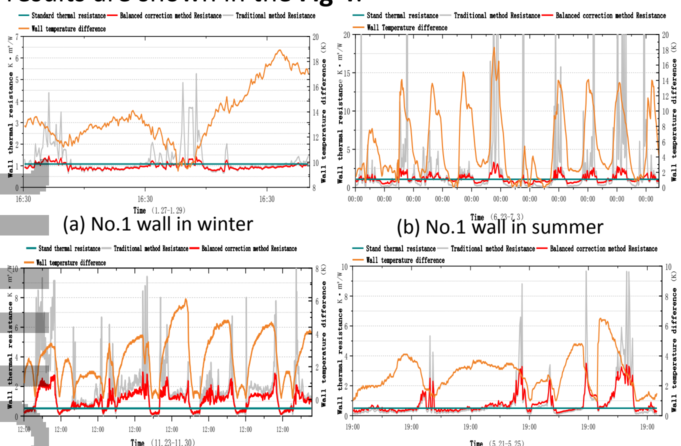


(a) No.1 wall in winter (b) No.1 wall in summer

(c) No.2 wall in autumn (d) No.3 wall in spring

Fig 3 Average correction curve of walls in four working conditions the curves after balance correction is more stable than the average curves, it effectively weakens the peak-to-valley difference. Therefore, using the corrected data to calculate can reduce the diffusion effect of heat flow in other directions, so that the calculated data is sufficiently close to the premise of "one-dimensional steady-state heat transfer", the results will be more accurate.

The hourly thermal resistances are calculated in order to compare the deviation and stability of the balance correction test method at each data point, the results are shown in the **Fig 4**:



(a) No.1 wall in winter (b) No.1 wall in summer (c) No.2 wall in autumn (d) No.3 wall in spring

Fig 4 Hourly thermal resistance curves of four working conditions

Comparing two hourly thermal resistance curves in the **Fig 4**, it is found that the calculation results of the balance correction test method is stable and sufficiently close to the standard thermal resistance at any moment, there also has fewer bad values with great deviation, while the calculation result of the traditional method has a larger error. Therefore, the calculation results of balance correction test method are more accurate and can shorten the selection of calculation period.

In addition to the hourly thermal resistance, use Eq(3) to calculate the average thermal resistance, and use the Eq(4) to calculate the thermal resistance error:

$$Error = \frac{|R-R_c|}{R_c} \times 100\% \tag{4}$$

The calculation results are shown in **Table 2**, refer to appendix. It can be found that the error of the thermal resistance value obtained by the balance correction test method is much smaller than the result measured by the traditional method.

Among them, the accuracy of Wall No. 2 in Autumn is poor. the main reason is that the heat flow through the inner wall and the outer wall is completely opposite at this time, and the direction of heat flow is both flowing into the wall or dissipating outside the wall at the same time, which violates "steady heat transfer". To sum up, in the test facing similar measurement conditions, consider correcting the state points whose heat flow direction is almost completely opposite to the magnitude, delete them, and then calculate the thermal resistance of the building envelope; Or use the more dominant unilateral heat flow for calculation, such as the outdoor heat flow in this working condition.

5. CONCLUSION

At present, when testing the thermal performance parameters of the building enclosure, there are problems such as large deviations in actual measurement results, heavy equipment, limited measurement environment in hot summer and cold winter areas, and low accuracy. Therefore, a balance correction test method based on the double-sided heat flow meter is proposed to optimize the current thermal performance detection and calculation methods of the building envelope in view of the above defects. The method is verified by 4 types of actual measurement conditions in the article, and the results show: (1) For the wall of steady state and unidirectional unsteady state heat transfer process, the balance correction test method can obtain better calculation results with errors of 6.48%, 5.56% and 5.8% respectively, which is more accurate than traditional heat flow meters method; (2) For the bilateral unsteady heat transfer process, there is a large error 75.38%. However, it is still better than the traditional method with an error of 109%, and further proposes that the solution of using the dominant heat flow to calculate the thermal resistance can reduce the deviation to 7.69%; (3) The hourly thermal resistance curve calculated by this method fluctuates steadily in any period and is closer to the true value, so the measurement time and calculation period can be shortened. In summary, this method can effectively, quickly and accurately calculate the thermal resistance of the building envelope.

ACKNOWLEDGEMENT

I would like to thank Professor Gong for his guidance and the partners for their support of the experimental data.

REFERENCE

[1] Trethowen H . Measurement errors with surface-mounted heat flux sensors. Building & Environment, 1986, 21(1):41–56

[2] Meng X , Yan B , Gao Y , et al. Factors affecting the in situ measurement accuracy of the wall heat transfer coefficient using the heat flow meter method. Energy and Buildings, 2015, 86:754–765
[3] Gaspar K , Casals M , Gangolells M . In situ measurement of façades with a low U-value: Avoiding deviations. Energy and Buildings, 2018, 170
[4] Ahmad A, Maslehuddin M, Al-Hadhrami L M. In situ measurement of thermal transmittance and thermal resistance of hollow reinforced precast concrete walls. Energy and buildings, 2014, 84: 132–141
[5] Asdrubali F , D'Alessandro, Francesco, Baldinelli G , et al. Evaluating in situ thermal transmittance of green buildings masonries—A case study. Case Studies in Construction Materials, 2014, 1:53–59
[6] Ficco G , Iannetta F , Ianniello E , et al. U-value in situ measurement for energy diagnosis of existing buildings. Energy and Buildings, 2015, 104(oct.):108–121
[7] Atsonios I A , Mandilaras I D , Kontogeorgos D A , et al. A comparative assessment of the standardized methods for the in–situ measurement of the thermal resistance of building walls. Energy and Buildings, 2017, 154:198–206
[8] Cesaratto P G , Carli M D , Marinetti S . Effect of different parameters on the in situ thermal conductance evaluation. Energy and Buildings, 2011, 43(7):p.1792–

APPENDIX

Table 1 The basic condition of the outer wall being tested

Number	basic structure	heat conductivity coefficient λ $W/(m \cdot K)$	standard thermal resistance $K \cdot m^2/W$	test condition
1	20 mm Cement mortar*2	0.93	1.08	**Working Condition One:** Winter; steady-state heat transfer **Working Condition Two:** Summer; One-way unsteady-state heat transfer
	40mm Inorganic insulating mortar	0.07		
	200mm Shale porous brick	0.63		
2	20mm Cement mortar*2	0.93	0.52	**Working Condition Three:** Autumn; Two-way unsteady-state heat transfer
	200mm Shale porous brick	0.63		
3	20mm Cement mortar*2	0.93	0.50	**Working Condition Four:** Spring; steady-state heat transfer
	240mm Clay solid brick	0.81		

Table 2 Comparison of thermal resistance calculation under four conditions

Working Condition	Characteristic	Standard Thermal Resistance $K \cdot m^2/W$	Traditional Method Resistance $K \cdot m^2/W$	Balanced Correction Method Resistance $K \cdot m^2/W$	Traditional Method Error	Balanced Correction Method Error
One	Steady state	1.08	1	1.01	7.41%	6.48%
Two	One-way steady state	1.08	0.62	1.14	42.59%	5.56%
Three	Two-way steady state	0.52	1.089	0.912	109%	75.38%
Four	Steady state	0.50	0.379	0.529	24.2%	5.8%

Table 3 Symbols and meanings in the Eq

Symbol	Meaning	Unit
q	Calculated heat flow after balance correction	W/m^2
T	Calculated Temperature difference after balance correction	K
q_b	Equilibrium heat flow	W/m^2
T_b	Equilibrium temperature difference	K
q_a	Average heat flow	W/m^2
T_a	Average temperature difference	K
$\bar{R}$	The average thermal resistance of the wall obtained by the balance correction test method	$K \cdot m^2/W$
i	i=1,2,3...n. The number of equilibrium heat flow points	-
j	j=1,2,3...m. Measurement points at all times	-