Study of the average heat transfer coefficient at different distances between wind tunnel models

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Abstract. The paper presents investigations of physical and climatic factors with regard to design and process variables having effect on heat transfer in the building model system at different distances between them in the airflow direction. The aim of this work is to improve energy efficiency of exterior walls of buildings. A method of physical simulation was used in experiments. Experimental results on the average values of the heat transfer coefficient in the building model system are presented herein. A series of experiments was carried out on a specific aerodynamic test bench including a subsonic wind tunnel, heat models and devices for giving thermal boundary conditions, transducers, and the record system equipment. The paper contains diagrams of the average heat transfer distribution at fixed Reynolds number and the airflow angle of attack; the average values of the heat transfer coefficient for each face and wind tunnel models as a whole at maximum, medium, and large distances between them. Intensification of the average heat transfer was observed on the downstream model faces depending on the distance between models.

1. Introduction
Researchers of the Construction Engineering Technology Department of Tomsk State University of Architecture and Building (Tomsk, Russia) are involved in a variety of problems dealing with the airflow structure [1], and the local and the average values of the heat transfer coefficient [2] with the aim to improve the design technique and energy efficiency of exterior walls.

In the literature, there are papers devoted to the study of heat transfer of bluff bodies [3–15]. Comparison of these data on the average heat transfer indicates a significant (more than 100%) variation in the given data.

All experiments on the average value of heat transfer coefficient were carried out using the subsonic open-return wind tunnel with air sucked through a duct. The experimental methodology and processing of wind tunnel test results are described in the work of Mokshin et al. [16].

In this study, the key parameter is calibration of wind tunnel models expressed by the distance ratio \( L1/a \) between models in the light (\( L1 \)) and the cross-sectional dimension of the wind tunnel model (\( a \)) equal to 50 mm.

2. Experimental
Figure 1 a, b shows schematic layouts of the test Model 2 relative to the test Model 1 at the airflow angle of attack \( \varphi = 0^\circ \).
Figure 1. Schematic layouts of the test Model 2 relative to the test Model 1 at the airflow angle of attack $\varphi = 0^\circ$.

Figures 2 – 4 contain plots of the average values of the heat transfer on faces depending on distance $L_1/a$ between wind tunnel models at the airflow angle of attack $\varphi = 0^\circ$. Also, for comparison, these Figures present data for $L_1/a \to \infty$ in the plane case of the single-model airflow [2].

Figure 2. Average heat transfer distribution on $(A - B)$ face of Model 2 at the increase of distance ratio $L_1/a$ at $\varphi = 0^\circ$, $Re = 4.25 \times 10^4$.

At the increase of distance ratio $L_1/a$ from 0.5 to 4.0 the average heat transfer on $(A - B)$ face of Model 2 also increases. At a maximum short distance of $L_1/a = 0.5$ the average heat transfer on $(A - B)$ face of Model 2 is 8.6% higher than on the same face of Model 1. This is because the flow separation occurred at the top of $(A - B)$ face of Model 2 and the arch-type vortex formed by Model 1. Their maximum effect on $(A - B)$ face of Model 2 was recorded at $L_1/a = 4.0$ [1] when the value of the heat transfer coefficient achieved its maximum, that is 27.1% higher than on $(A - B)$ face of Model 1. At distance ratio ranging between 4.0 and 24.0 the flow separation force at the top of $(A - B)$ face of Model 2 decreases as well as the effect from the arch-type vortex formed by Model 1. The average value of the heat transfer coefficient on $(A - B)$ face of Model 2 is reduced and thereby approximates to that of $(A - B)$ face of Model 1.
Figure 3. Average heat transfer distribution on \((B - C)\) and \((D - A)\) faces of Model 2 at the increase of distance ratio \(L1/a\) at \(\varphi = 0\). \(Re = 4.25 \times 10^4\).

Since in Figure 3 the average heat transfer distribution over faces \((B - C)\) and \((D - A)\) is identical, the description below will refer to face \((B - C)\) only.

At distance ratio \(L1 / a\) ranging between 0.5 and 6.0 a gradual increase of the average heat transfer is observed on \((B - C)\) face of Model 2. At \(L1 / a = 0.5\) the average value of the heat transfer coefficient on \((B - C)\) face of Model 2 is 21.3 % higher than on the same face of Model 1. It can be explained by the fact that at a maximum short distance between the models, recirculation regions formed by Models 2 and 1 and the flow separation formed at the top of \((A - B)\) face of Model 2 noticeably affect the bottom of \((B - C)\) face. At distance ratio \(L1 / a = 6.0\) these forces have maximum effect on \((B - C)\) face of Model 2. Average values of the heat transfer coefficient on \((B - C)\) face of Model 2 increase by 35.5 % as compared to that ones obtained from \((B - C)\) face of Model 1. At a distance between the wind tunnel models ranging from 6.0 to 27.0 the effect from recirculation regions and the flow separation on \((B - C)\) face of Model 2 is reduced. The average value of the heat transfer coefficient on \((B - C)\) face of Model 2 also decreases, thereby approximating to that of \((B - C)\) face of Model 1.

Figure 4. Average heat transfer distribution on \((C - D)\) face of Model 2 at the increase of distance ratio \(L1/a\) at \(\varphi = 0\). \(Re = 4.25 \times 10^4\).
At a distance between the wind tunnel models ranging from 0.5 to 2.0 a sharp increase of the average value of the heat transfer coefficient on \((C-D)\) face of Model 2 is observed, the value of which is lower than on the same face of Model 1. At distance ratio \(L1/a = 0.5\) the heat transfer coefficient of \((C-D)\) face of Model 2 is 9.9% lower than on the same face of Model 1. At a maximum short distance, the arch-type vortex formed by Model 2 is less intensive than that one formed by Model 1. In increasing the distance ratio up to 2.0 the arch-type vortex formed by Model 2 promotes a stronger effect on Model 2. At that, average values of the heat transfer coefficient on \((C-D)\) face of Model 2 are practically the same (0.46% difference) as on \((C-D)\) face of Model 1.

At a distance between the wind tunnel models ranging from 2.0 to 4.5 average values of the heat transfer coefficient on \((C-D)\) face of Model 2 are being sharply increased, and become higher than on the same face of Model 1. At distance ratio \(L1/a = 4.5\) the heat transfer coefficient of \((C-D)\) face of Model 2 is 5.7% higher than on the same face of Model 1. At this distance, the intensity of the arch-type vortex formed by Model 2 exceeds the similar arch-type vortex formed by Model 1.

At a distance between the wind tunnel models ranging from 4.5 to 12.0 the intensity of the arch-type vortex formed by Model 2 on its \((C-D)\) face becomes lower. The average value of the heat transfer coefficient on \((C-D)\) face of Model 2 is reduced, thereby approximating to that of \((C-D)\) face of Model 1.

At a distance between the wind tunnel models ranging from 0.5 to 5.5 the average value of the heat transfer coefficient increases on the entire Model 2. At a maximum short distance \(L1/a = 0.5\) the heat transfer coefficient on Model 2 is 9.7% higher than on Model 1. This is because Model 2 is affected by arch-type vortices formed by Model 1 and the strong flow separation occurred at the top of Model 2. The ultimate effect from these phenomena is recorded at a distance ratio \(L1/a = 5.5\) when the average value of the heat transfer coefficient achieves its maximum, i.e. 24.9% higher than on Model 1.

At a distance between the wind tunnel models ranging from 5.5 to 27.0 these forces become lower, and the average value of the heat transfer coefficient on Model 2 is reduced, thereby approximating to that of Model 1.

The diagrams of the average heat transfer for each face of Model 2 are similar to those of Model 1 at different model calibrations, namely: \(L1/a = 24.0\) for \((A-B)\) face; \(L1/a = 27.0\) for \((B-C)\) face; \(L1/a = 12.0\) for \((C-D)\) face. Average values of the heat transfer coefficient on Model 2 and Model 1 are identical at a distance ratio of 27.0 and larger.

This identity is being observed at the subsequent increase of the distance ratio up to \(L1/a = 30.0\).
Figure 6 demonstrates the summary plot of the average heat transfer distribution over Model 2 faces at the increase of distance ratio $L1/a$ at $\varphi = 0^\circ$, $Re = 4,25 \times 10^4$.

As shown in Figure 6, at the increase of distance ratio $L1/a$ from 0,5 to 30 the airflow behavior is changed between the wind tunnel models and on lateral faces of Model 2. This leads to the intensification of the average heat transfer on Model 2 faces, while the distance between wind tunnel models increases. At the same time, in varying the distance ratio $L1/a$ not more than by 10%, heat transfer on $(C–D)$ face of Model 2 changes insignificantly.

3. Conclusions
1. At a maximum short distance ranged from 0,5 to 6,0 the clear-cut distinction between the average values of the heat transfer coefficient on Model 2 faces was observed. The maximum average heat transfer was on $(A–B)$ face of Model 2, while the minimum was on its $(C–D)$ face. As for lateral faces $(B–C)$ and $(D–A)$ of Model 2, the heat transfer value varied between those on $(A–B)$ and $(C–D)$ faces of Model 2.
2. At a medium distance $L1/a$ ranged between 6,0 and 21,0 the average heat transfer was more intensive on Model 2 faces. At first, the heat transfer on $(B–C)$ and $(D–A)$ faces of Model 2 at distance ratio $L1/a = 6,0$ was average as compared to faces $(A–B)$ and $(C–D)$ of Model 2, however, at $L1/a$ increase up to $12,0 \div 15,0$ it achieved its relative maximum. Then, at $L1/a$ increase from 15,0 to 21,0 the average value of heat transfer lowered sharply, and its contribution to the total heat transfer on the entire Model 2 became minimum.
3. At a maximum distance $L1/a$ ranged from 21,0 to $\infty$, the clear-cut distinction between the average values of the heat transfer coefficient was observed on Model 2 faces. The maximum average heat transfer was on $(A–B)$ face of Model 2, while the minimum was on its lateral faces $(B–C)$ and $(D–A)$. On face $(C–D)$ of Model 2, it was lower than on face $(A–B)$ of Model 2 (some 3,0 % difference).

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