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Modelling of Air Fluxes and Temperature Distribution in Heated Rooms

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Abstract

The averaged distributions of temperature and turbulent air fluxes in living rooms are investigated in 2D approximation using the commercial software ANSYS/FLOTRAN. These distributions are calculated in dependence of placement and temperature of heaters, heat transfer coefficients of building constructions and ventilation. The influence of these factors on air circulation and on related heat fluxes through insulating building constructions is analysed. The possibilities of saving heat are shown, maintaining the conditions of thermal comfort in room.

Introduction

The placement of heaters and their operating temperature essentially influence the distribution of temperature in living rooms. The distribution of temperature is strongly related with the character and intensity of air fluxes. These air movements determine the thermal convection, controllable and uncontrollable heat influx through the openings of ventilation and holes in the walls of the room, windows, floor and ceiling of the room. Heat consumption for maintaining thermal comfort increases essentially, which causes an increasing the heat transfer coefficient U (W/m^{2}K) through insulating constructions, especially through outside wall [1]. Heat transfer through boundary layers increases also at an intense heat flux at building constructions. As a result, heat transfer coefficient at surface α_I can differ essentially from standardised value of inner rooms α_I=8.1 and vary on the height of building element (especially for outside wall and window). It is possible to decrease the intensity of fluxes at the vicinity of insulating surfaces by appropriate choosing of the placement of heating facilities and opening of ventilation, and by integrating in windowsill. Therefore, it is possible to decrease the coefficient of heat transfer and the total heat leakage of the building at fixed heat transfer coefficient of building constructions. The optimal placement of heaters and ventilation system allows maintaining the thermal comfort in the room with a reduced heat consumption.

The modelling of thermal situations of individual rooms is also important for specifying the (integral) model of heat balance [2]. The last model allows to determine the total heat leakage, i.e. heat consumption of the building. The differential modelling can be used for specifying

- heat transfer coefficient at surface α_I and heat leakage through outer building constructions at different characteristic situations;
- heat exchange between building blocks with different temperatures, e.g. between living rooms and hallway.

1. **Numerical Model**

1.1. Description of Modelled Room

The calculations are performed for the room shown in Fig. 1. The room has a height 3 m and depth 6 m. Heat transfer coefficient $U_d=\lambda_{eff}/d$ for different insulating building constructions are different, where λ_{eff} is the effective heat conductivity, *d* – thickness. Only one of the walls (M3) has a window (M4) and boundary with outside. A heater is placed near this wall. Heat transfer coefficients of building constructions are shown in Tab. 1. It is important that the heat transfer coefficient at the heater is very high in variants 1 – 3, while in variants 4 – 6 it corresponds to planned building-normatives of Latvia. The heat transfer coefficient of window is higher in variants 4 – 6. The problem is simplified assuming that the considered room is one of many, i.e., heat flux through the side walls is practically absent. The temperature of rooms upstairs or downstairs of the room is chosen at condition of thermal comfort – *T*=293 K, while temperature behind the frontal wall W3 is chosen lower: *T*=285 K (e.g. hallway). The outside temperature, i.e., behind the wall W4 correspond to winter conditions – *T*=263 K.

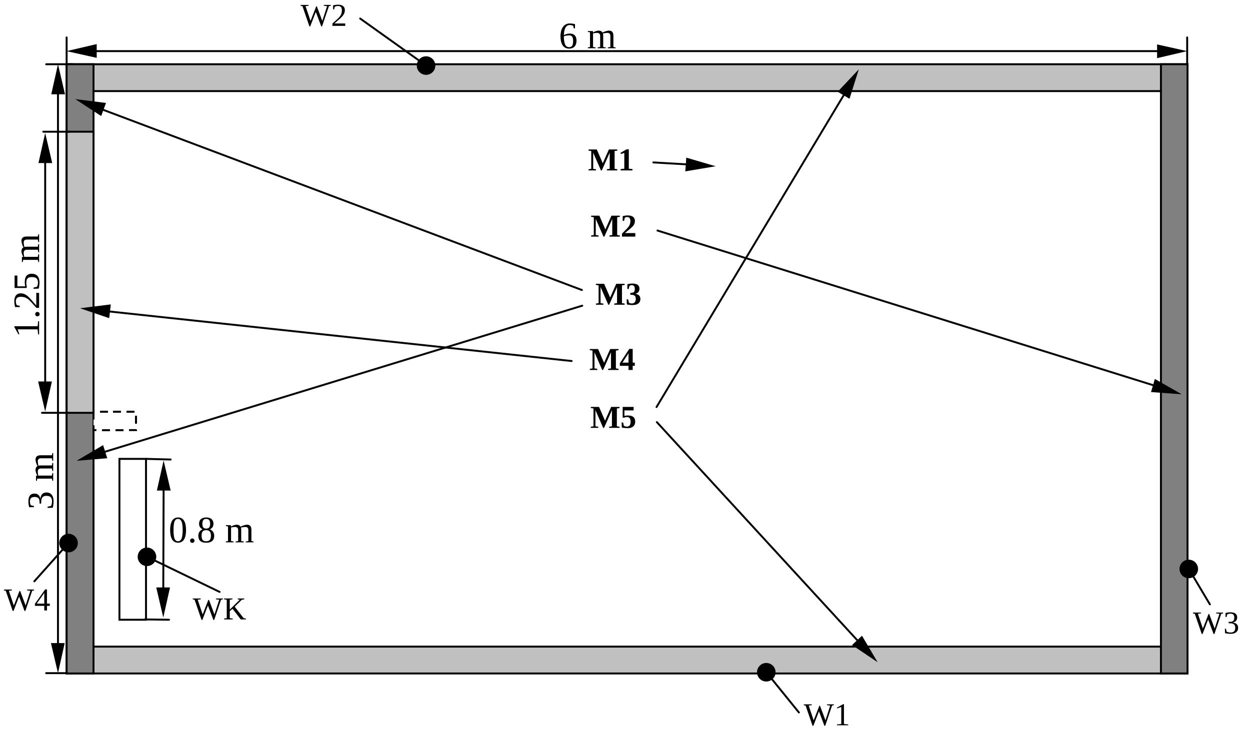


Fig. 1. Layout of building elements in modelled room

The standardised value of heat transfer coefficient at the surfaces of building constructions bordering with other room is chosen α_I=8.1 W/m^{2}K while for constructions bordering with outside - α_I=23.2 W/m^{2}K. Thus, the heat exchange through the inner surfaces of building constructions should be determined by modelling. The surface of the heater (WK) is set to be with constant temperature or constant heat flux density (see WK row of Tab. 1). The physical properties of air in the room are shown in Tab. 2.

1.2. Mathematical Model

Airflow in a room depends both on convection created by the temperature difference and on air exchange between openings of building constructions (holes, natural and artificial ventilation, etc.). The velocity of air flux can exceed 0.1 m/s (*Re*>10^4) at typical conditions.

Tab. 1. Properties of building elements in 6 variants of modelling

Symbol	Description	Variants					
		1	2	3	4	5	6
M2	Wall with another room, U_d, W/m^{2}K	1.2	1.2	1.2	1.2	1.2	1.2
M3	Outside wall, U_d, W/m^{2}K	1.5	1.5	1.5	0.33	0.33	0.33
M4	Outside window, U_d, W/m^{2}K	2.5	2.5	2.5	2.5	6.0	6.0
M5	Wall with another room, U_d, W/m^{2}K	0.8	0.8	0.8	0.8	0.8	0.8
WK	Temperature, K	333	323	313	313	-	323
	Heat flux density, W/m^2	-	-	-	-	57.5	-

Parameters	Convection at another room	Convection at another room	Convection at outside
Symbol	W1, W2	W3	W4
Bulk temperature, K	293	285	263
Heat transfer coefficient at surfaces α, W/m^{2}K	8.1	8.1	23.2

Thus, the air flux has a turbulent character. The traditional differential equations are used to describe the quasi-stationary behaviour of temperature and averaged turbulent flux. The equations describing the transfer of turbulent kinetic energy and intensity of dissipation are added, too, in order to determine the viscosity and heat conductivity required in the approximation of k-ε model [3]. The above mentioned assumption about cancelling of fluxes between neighbouring rooms with equal conditions allows to use 2D approximation.

The temperature distribution should be determined both inside the room and in building constructions, because the convection type boundary conditions $\lambda \cdot \partial T/\partial n = \alpha(T - T_\infty)$ are set for the temperature at the outer boundary of building constructions. The heat radiation of the sun through the window is ignored in order to simplify the model.

Tab. 2. Properties of material M1 (air).

density	ρ=1.11 kg/m^3
dynamic viscosity	μ=2·10^{-5} kg/m·s
volumetric expansion	α=0.0034 K^{-1}
heat conduction	λ=0.02454 W/m·K
heat capacity	c_p=1007 W·s/kg·K

1.3. Numerical Realisation

The software packet of modelling ANSYS/FLOTRAN is applied to obtain both the stationary temperature distribution and averaged fluxes in approximation of k-ε model. The discretisation is performed with elements of varying size. The size of the elements in the middle of area does not exceed 5 cm. This size changes down to 5 mm at the vicinity of solid objects. Therefore, the total number of elements in 2D area is approximately $2 \cdot 10^5$.

The boundary conditions of the third type (convection) for temperature at all surfaces of building constructions disimproves the convergence of iteration process. The required time of calculations on Pentium III 600 MHz for each variant is 40-60 hours. The difference between supplied heat of the heater and heat leakage from the outer surfaces of building decreases beneath 10 % during each simulation.

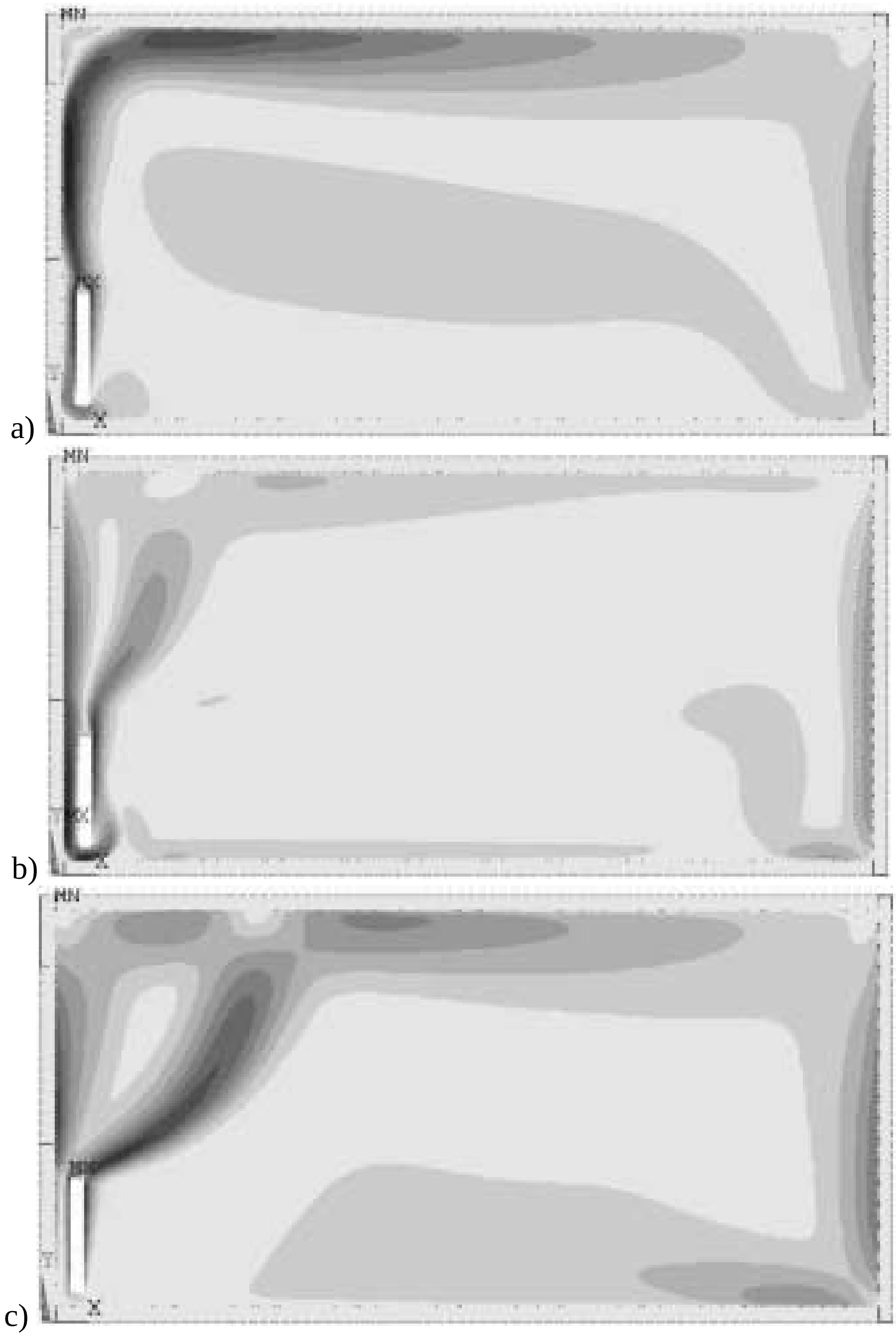
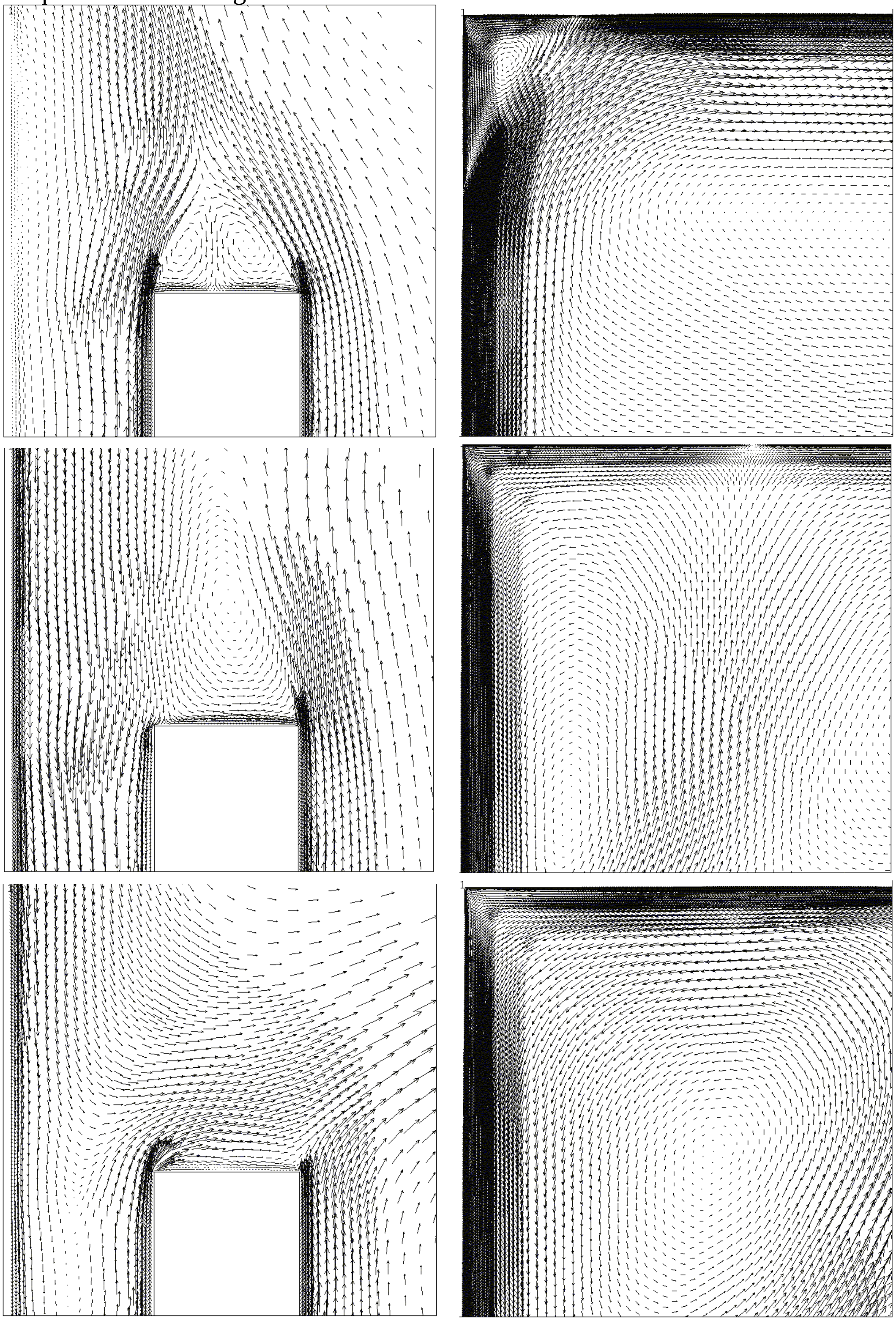


Fig. 2. Stationary distribution of the module of velocity in the room. a, b, c correspond to variants 1, 3, 4, respectively.

2. Results of Modelling

2.1. Velocities and Temperature Distributions

The character of air fluxes near the outer wall and convectors changes essentially decreasing the temperature of the convector at fixed heat transfer coefficient of building constructions (see Fig. 2a, b). The upward flux at the heater dominates at high temperature of the heater (*T*=333 K). This is upward flux is slowed down at the vicinity of outside wall (Fig. 3a and 4a). The upward flux of warm air declines from outside wall decreasing the temperature of the heater (Fig. 3b and 4b). Simultaneously, the downward flux of cold air develops along the window. In the first case, two almost symmetric vortices of secondary flux appear above the heater (Fig. 3a). In the second case with lower temperature of the heater, only one centre of vortex can be observed (Fig 3b) and the intensity of flux above of it is small. The direction of dominant flux in the gap between the heater and the wall changes to opposite one decreasing the temperature of the heater (Fig. 5a and 5b). This is the consequence of thermo-gravitational forces and inertia of fluxes.



a)

b)

c)

Fig. 3. (left) Air flux pattern above the heater. a, b, c correspond to variants 1, 3, 4, respectively.

Fig. 4. (right) Air flux pattern at top of the room at outside wall. a, b, c correspond to variants 1, 3, 4, respectively.

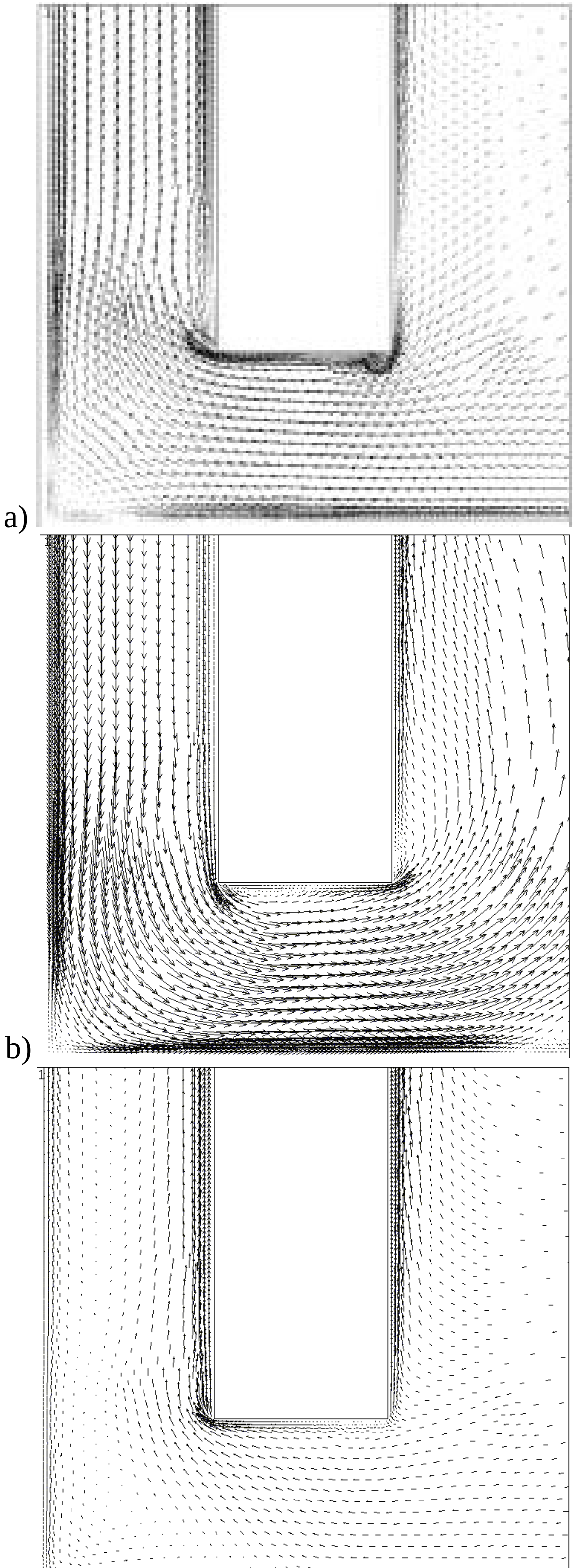


Fig. 5. Air flux pattern below the heater. a, b, c correspond to variants 1, 3, 4, respectively.

The upward flux of heat air declines even more into the middle of the room (Fig. 2c and 3c) decreasing the heat transfer coefficient of the outside wall at the vicinity of heater and increasing the heat transfer coefficient of the window (variant 4) at the same temperature. The flux intensity between the heater and outside wall decreases significantly in this variant (Fig. 5c). Consequently, the heat leakage to the outside decreases by more than 30 % in spite of higher heat transfer coefficient of the window. The overall heat leakage decreases, too. As a result, even the temperature in the middle of the room even increases slightly (< 1K). The similar effect that declines the upward flux of heat air from outside wall is insertion of windowsill.

The intensity of thermo-gravitational forces increases in the vicinity of the heater increasing its temperature from 313 K to 323 K at such conditions with increased heat transfer coefficient of windows, but decreased heat transfer coefficient of outside wall. Consequently, the distribution of air fluxes approaches qualitatively the results of variant 1 with upward flux of warm air along the outside wall. Only the intensity of maximal flux is somewhat lower (v_{max}≈0,5 m/s).

Such high flux velocities are observable only in a small area near the heater and outside wall – the velocities of air flux in the middle of the room does not exceed 5 cm/s. The vertical variation of temperature does not exceed 2–3 K in the middle of the room outside the thermal boundary layers. The variation of temperature along the depth at height 1.5 m does not exceed even 1 K in the middle of the room.

2.2. Heat Exchange

Heat leakage through the outer wall exceeds several (3–5) times the heat leakage through the frontal wall bordering with room which has lower temperature (Tab. 1). That is valid both for high heat transfer coefficient of the outside wall (variants 1 – 3) or the window (4 – 6), because of low temperature outside. The comparison of heat fluxes is shown in Tab. 3. The temperature at the vicinity of the floor is lower. Therefore, the decrease of the heating power causes the flux through the floor to invert direction and become negative – heat is transferred from the room downstairs. The temperature of ceiling is higher than the average. Hence, heat leakage through them tends to zero at both sides of the ceiling decreasing the supplied heating power and equalising the conditions at both sides of building construction. The supplied heat and heat leakage from the room decreases approximately by 30 %, decreasing the temperature of the heater by 20 K. As a result, temperature in the middle of the room decreases less than by 4 K. Heat leakage to the outside decreases by more than by 30 % decreasing the heat transfer coefficient of the outside wall 5 times at the vicinity of heater (see Tab. 1) at constant temperature of the heater. The simultaneous increase of average temperature in the room increases heat leakage to the neighbouring rooms. Consequently, the overall decrease of heat leakage is small.

The actual conditions of heat exchange are ignored at the vicinity of the heater fixing the heat flux on the surface of the heater (variant 5). In this case, the heat flux to the outside wall decreases, while heat flux to the middle of the room increases. As a result, characteristic temperature in the middle of the room increases slightly, while heat leakage to the outside decreases a little a bit at the same heating power.

Tab. 3. Comparison of heat fluxes

Variant	Surface	Heat fluxes [W]
1	W1	8.2
	W2	19.2
	W3	34.9
	W4	161.6
	Total	223.9
2	W1	-2.0
	W2	6.4
	W3	27.3
	W4	145.3
	Total	177.1
3	W1	-5.6
	W2	4.0
	W3	26.8
	W4	128.1
	Total	153.3
4	W1	2.5
	W2	8.4
	W3	6.8
	W4	82.9
	Total	120.8
5	W1	0.6
	W2	7.1
	W3	26.1
	W4	80.2
	Total	114.0
6	W1	7.1
	W2	15.9
	W3	31.1
	W4	100.8
	Total	154.9

Conclusions

The calculations demonstrates that the distribution of thermo-gravitational forces and the related character of air fluxes in the room can be manipulated by changing the temperature of the heater and heat transfer coefficient of building constructions (especially of outside wall and window). It allows decreasing the heat leakage and required heating power to maintain the condition of thermal comfort in the room.

References

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