Sick Building Syndrome Suppressing by Room Ventilation

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Abstract: - The paper deals with the problem of so-called “sick building syndrome”, typical for air-tight rooms and buildings without natural or artificial ventilation where the pollutant concentrations (heat, moisture, CO_2, etc.) are increasing and make problems, sometimes dangerous, during the use of the room. Typical problems are for instance higher air humidity, water condensation, mould growth etc. The presented results of numerical flow simulations, simulated for the conditions of Central Europe, are made for the cold winter period and present that simple measures can remedy such unsuitable state, practically without investing expenses and without consumption of operational energy – not any known air conditioning devices used. Important differences between ventilation by large opening and narrow slots are presented, too.

Key-Words: - Room ventilation, Pollutant concentration, Flow simulation, Self-ventilation, Sick building syndrome

1 Introduction

The air-tight outer housing is typical for new or reconstructed buildings, due to tight windows, outer thermal insulation, etc. It is good for the reduced heat consumption in winter period but there are some disadvantages, in general, too, known in general as the “sick building syndrome” [1]. For instance, the higher air humidity could result in water vapor condensation in the colder outer corners of the observed room and consequently in mould growth, or in assembling rooms (classrooms, etc.) without ventilation, the concentration of CO_2 is increasing quickly over the hygienic limits and is the reason of fatigue, headache etc., or due to internal heat sources, the room temperature is increasing and it is necessary to keep it on a suitable level [2]. Many other pollutants can be present in observed buildings, as for instance formaldehyde, radon, bacteria etc. [11], [12], but it is over the extent of this short paper.

The design of air conditioning units, taking into account all such pollutant sources, is well- known. Many producers offer many different units for various kind of use. In general, the costs are significant – not only investment, but operational, too. In reconstructed buildings could not be space enough for such equipment.

This paper is focused on standard rooms without air conditioning, using natural or forced ventilation, only. Presented results describe, how to remedy the so-called sick building syndrome and without any expenses to get and keep healthy living environment. The paper contains examples of the ventilation by large openings, typically as open window, compared with ventilation by small openings, typically as ventilating slots. The problem should be solved as unsteady case. The presented solution is focused on maintenance of suitable relative humidity in the room, because another pollutants in here observed room were not important.

2 Ventilation by large openings

2.1 General model description

For the comparison of various designed schemes of ventilation, there are used some general principles. Main dimensions of the observed room are as follows: the ground plan of 4x4 m and height of 2.65 m, wall thickness of 0.5 m and open window of 1.4x1.1 m, its lower side at 0.85 m from the floor. To reduce the calculating time, there is used a symmetrical half of the room so that the ventilating opening is situated in this plane of symmetry. Of course, using the cross flow, the ventilation effectivity will be higher, but in such a case, the full 3D model should be used.

From the outer side, some outer volume should be connected so that the outer boundary conditions do not affect immediately the flow field inside the room. The flow field image in such outer volume is not fully correct; it serves for inlet of outer air inside and for

exhaust of inner air outside. Really, the outer volume is very wide and its flow field is not matter of this paper.
Mesh in such simple geometry contains hexahedral elements, reasonably smaller in the opening area.
The boundary conditions for gravity circulation remain the same, too, 0°C for outside air and +22°C for inside air, isobaric model of atmospheric pressure 100 kPa is used. In some cases the pressure or suction effect of wind, chimney etc. is added as a small pressure difference of several pascals. For the information, the value of 0.1 Pa corresponds to the velocity of 0.4 m/s – in ventilating technology, the air flow less than 0.5 m/s is considered as non-obtrusive.
As to the turbulence model, After some numerical experiments the turbulence model k-ε is assigned as suitable for use. The Reynolds number in a large cross section of the modeled room is quite high and more, on the surface of the inlet narrow flow, mixing with the inner air in the room, the turbulences are present, too. The tested laminar model has not a good convergence of the solution and more, results of both models are very similar, see Fig. 14. For better convergence, the parameters of under-relaxation are slightly reduced.
For large ventilating openings, the unsteady solution is used, there is observed the decreasing of the average inner temperature in a ventilated room since the start of the ventilation period and after this result there is estimated the ventilation intensity. The needed heat input is calculated for reheating the ventilated volume on its initial state during the same time period as the ventilation period.
The next prospective differences of models are mentioned in the actual solution.

2.2 The short overview of used procedure

Several basic formulas are used for heat and flow balances evaluation, outgoing from mass and energy conservation law (continuity and Bernoulli's equation), cited in every handbook of fluid mechanics, for instance [3], [4] etc.
Driving pressure gradient for air movement during natural ventilation (aeration) is given either by densities differences between outer and inner air densities ρo and ρi

$$\Delta p = g \cdot H \cdot (\rho o - \rho i), \quad (1)$$

which depend on air temperature after the state equation of gas

$$\rho = p / (r \cdot T), \quad (2)$$

or the pressure gradient is defined as the influence of wind velocity

$$\Delta p = \rho \cdot w^2/2, \quad (3)$$

or as any combination of both influences can be used.
In this paper is not discussed forced ventilation using fan.
The volume flow of ventilating air is given by the continuity equation (mass conservation law)

$$m = \rho \cdot S \cdot w \text{ [kg/s]} \quad (4)$$

and last but not least, the heat input necessary for later reheat of the exchanged air volume in the ventilated room on its original temperature, depends on the mass flow and on the temperature change ΔT in the room during the ventilation period

$$Q = m \cdot cp \cdot \Delta T \text{ [W]}. \quad (5)$$

This formula invalidates the frequent public statement that the room ventilation needs too much energy for reheat of exchanged air. It is known that thermal capacity of air is cp = 1 kJ/(kg.K) approx. or 0,84 – 0,91 kJ/(m^3.K), depending on the temperature after (2). By contrast, the thermal capacity of porous masonry is typically 500 kJ/m^3, it means that during short time of room ventilation the wall temperature does not change practically due to accumulated heat in the masonry mass.
As above-mentioned, used formulas are simple, but it is not known, if people does not know them or they does, but does not respect?! This paper would like to educate a little the public population in the field of suppressing of serious problem of so-called sick buildings.
Results of realized numerical simulations are presented in the lengthwise plane of symmetry. Several typical flow field parameters are usually used – velocity, temperature, directional field, together with the main values for the balances of mass and heat flow.

2.3 One open window (case 01)

The window in the left wall is open, the right wall is shut, the room is air-tight (theoretical condition). The scheme of the used geometry is evident from the following images of the resulted flow fields.
In this case, the air movement arises by the difference of densities between the cold outer air and the warm inner air, see (1). Just after the window opening, both airs are mixing together, after the temperatures equalizing the movement stops. Therefore, the case should be solved as unsteady.
As an illustration, only, Fig. 1 presents the temperature field in the time of 4 minutes after the window opening. The cold air is flowing through the window down and right and is accumulating in the lower part, the warm air remains in the upper part of the room.

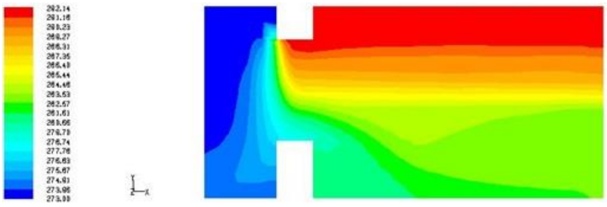

Fig. 1 Temperature field after 4 minutes

The same situation shows the field of horizontal component of velocity in Fig. 2.

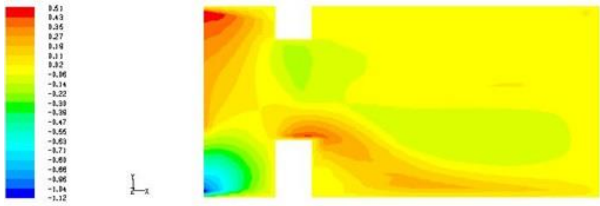

Fig. 2 Velocity field after 4 minutes

The main cold flow is flowing along the lower side of the window inside and some volume of the inner warm air is flowing out along the upper side of the window.

Remark: Adding any slight pressure gradient from the left side into the air-tight room, such a gradient prevents the outflow as described above and the total air exchange is smaller. But such an absolutely air-tight room is a theoretical possibility, only.

2.4 Two open windows (case 02)

Two open windows are situated in the opposite walls, with alternatively added pressure difference (air draught or wind effect). The scheme of the used geometry is evident from the following images of the resulted flow fields.

2.4.1 Zero pressure difference

If the zero pressure difference is defined, the case is similar to the previous – after windows opening the inner and outer air are mixing in the room. From both opposite openings, the same volume of the cold air is coming into the room, therefore, the flow field is symmetrical along the cross vertical plane.

The results are presented here after the time period of 4 minutes of ventilation, only. In the area of the temperature field in Fig. 3, the area of initial warm inner air is reduced and remains at the ceiling, only, the area of cold outer air is increasing in the lower part.

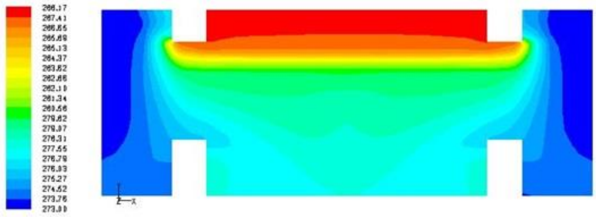

Fig. 3 Temperature field after 4 minutes

The field of the horizontal component of velocity in Fig. 4 is perfectly symmetrical, the absolute value of intruding outer air velocity is decreasing in time.

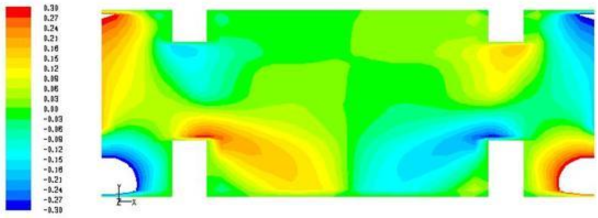

Fig. 4 Velocity field after 4 minutes

2.4.2 Influence of air draught

Really, every room has any leakage, therefore any small pressure difference by wind effect or else could be added. For the previous case, there is added the non-zero pressure difference of 0.1 Pa (theoretically corresponding to the velocity of 0.4 m/s). The flow field is changed as follows:

The temperature field in Fig. 5 is slightly asymmetric with a visible tendency of the flow from left to right. In the velocity field, Fig. 6, the cold air is mainly flowing in from the left side and the warm inner air is mainly flowing out to the right side.

The same situation presents the directional field colored by temperature, Fig. 7, in the middle of the room there is visible large "ventilating" vortex.

As mentioned above, the field in outer volume is deformed by the outer boundary conditions, this part is not correct and is used for suppressing of inlet/outlet boundary conditions influences on the image of the flow field inside, only.

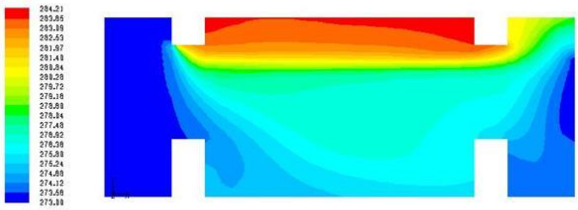

Fig. 5 Temperature field after 4 minutes

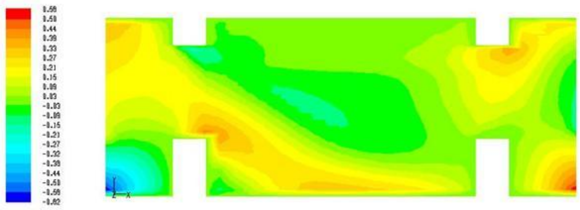

Fig. 6 Velocity field after 4 minutes

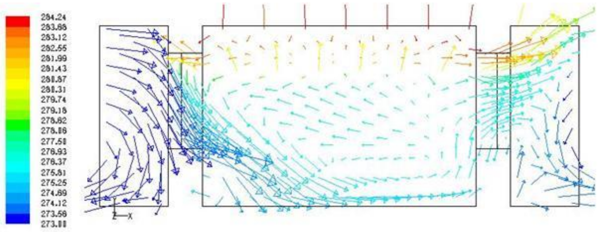

Fig. 7 Directional field after 4 minutes

2.5 Ventilation by tilted window(s) (case 03)

Instead of large window opening there is frequently used the ventilation by a narrow gap on the upper edge of the tilted window, only.

The model contains the constant gap of a height of 100 mm, only, without side wedges along the tilted window wing. The scheme of the used geometry is evident from the following images of the resulted flow fields.

In this case, the narrow opening, there is not available a sufficient effective height for creating the needed pressure difference after (1) so that the ventilating flow in such an opening is very small. And more, the total cross section of the flow (4) is smaller, too. Such kind of ventilation in the air-tight room is absolutely ineffective.

2.5.1 One opening

In this case, the only one ventilating gap is open on the left side. In this narrow opening the ventilating effect is very small, therefore in the lengthwise section of the room (as in the previous paragraphs), not any details are visible and so the results are not presented here.

Instead of it there are presented cross views on the flow parameters in the plane of such ventilating gap.

On the temperature field Fig. 8 the cold air is flowing in in the lower part, warm flow is flowing out in the upper part.

The field of the horizontal velocity component in Fig. 9 (plus values = inlet in the lower part, minus values = outlet in the upper part), values of some cm/s, only.

The field of turbulent kinetic energy in Fig. 10 presents the maximum disturbance along the lower edge, where the outer air is flowing in.

All results are presented for the time of 4 minutes of an unsteady solution again.

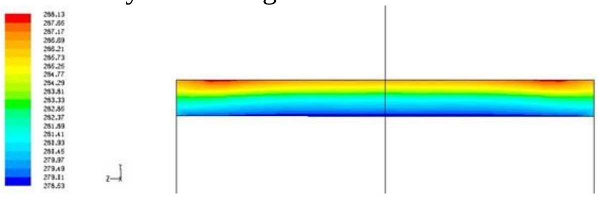

Fig. 8 Temperature field in a narrow gap

Cold inflow in the lower part, warm outflow in the upper part. The image characteristics is similar to the large open window, but the total air flow is small.

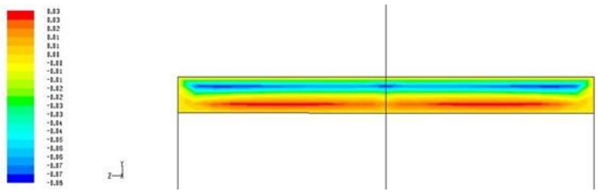

Fig. 9 Horizontal velocity component

Negligible values (cm/s) in a narrow gap, comparing with the range of dm/s from the Fig. 6.

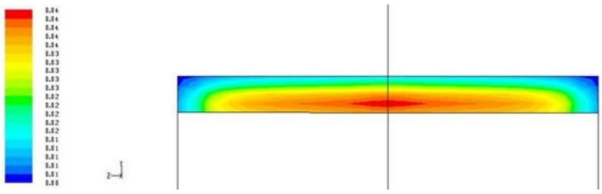

Fig. 10 Field of the turbulent kinetic energy

Maximum is along the lower edge of the narrow opening, the use of the turbulent model is correct.

2.5.2 Two openings in opposite walls

Here are open two ventilating gaps in the opposite walls and more, from the left side, there is defined a small overpressure of 0.1 Pa (corresponding to the velocity of 0.4 m/s), as in the Par. 2.4.2. Comparing with the previous case, the ventilating flow is here stronger. Results of this unsteady solution are presented for the time of 4 minutes from the start of ventilation.

Fig. 11 presents the temperature field, due to the added driving pressure gradient from the left side, the field is shifted a little to the right. But the area of fresh (cold = blue) air is much smaller, comparing with the previous case of large windows in Par. 2.4.2.

Fig. 12 presents streamlines of incoming air from the left gap – directed to the right and down. The Fig. 13 presents streamlines of exhausted air to the right gap along the ceiling. It is clear that the room volume affected by ventilating flow from two narrow gaps is reduced and imperfect.

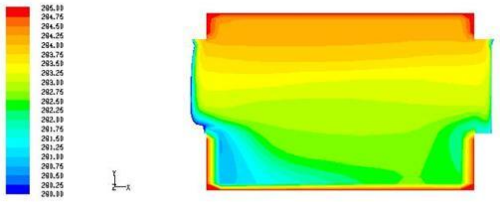

Fig. 11 Temperature field – two narrow gaps

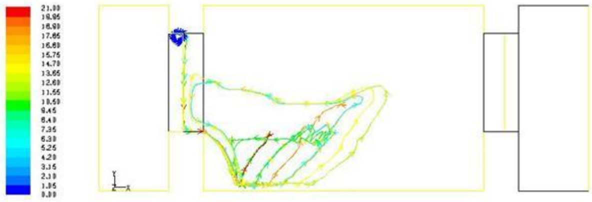

Fig. 12 Streamlines from the left gap into the room

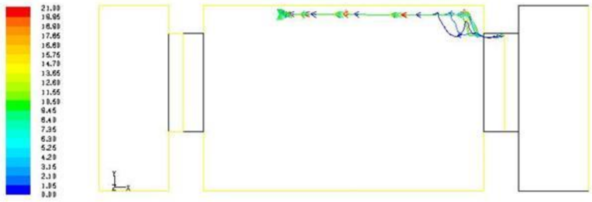

Fig. 13 Streamlines into the right gap

Remark: The case of two open ventilating gaps without the defined overpressure is analogous to the case of two open windows, see Par. 2.4.1. Due to a very small ventilating effect of such case, the results are not presented here.

2.6 Summary of the results

The previous flow field images are completed by following summary graphs, presenting the results of unsteady solution with gravity circulation, i.e. for outer air 0°C, inner air 22°C, without internal heat sources, modelled as empty room. In some cases it is added the influence of small air draught of 0.1 Pa.

Next solved cases are recorded in the common graphs Fig. 14 to Fig. 16 during the ventilating period of 4 minutes.

<u>Case „1 lam“, „1 k-ε“</u> – one open window, without air draught (air-tight room). It is the testing case of two different turbulence models – laminar and turbulent k-ε. Differences are not important.

<u>Case „2“</u> – two open windows in the opposite walls, no air draught, no inner heat source. The air exchange is larger but not doubled, comparing with one open window.

<u>Case „21“</u> – for the case „2“ is added air draught of 0.1 Pa from the left side – the ventilation is more intensive.

<u>Case „3“</u> – one open ventilating gap, no air draught. Comparing with the large window cross section, the air exchange and the practical effect, too, are negligible.

<u>Case „32“</u> – two open ventilating gaps in the opposite walls. Added air draught of 0.1 Pa causes a larger air flow. But comparing with the large window cross section, the air exchange is negligible.

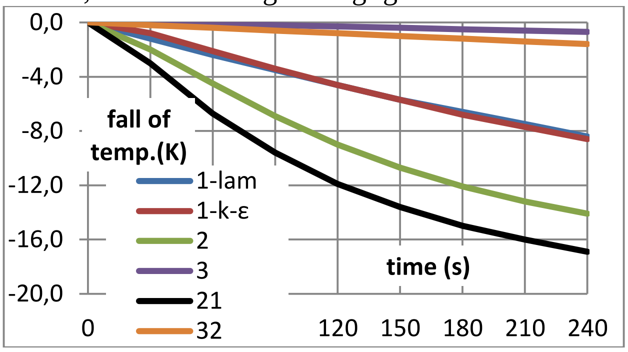

Fig. 14 Temperature decreasing during ventilation

The Fig. 14 presents the decreasing of inner air temperature. Of course, the value of temperature decreasing is proportional to the ventilation intensity. The inner temperature is decreasing in time, due to the mixing of inner and outer air, therefore the driving pressure gradient (1) is decreasing in time, too. After the very long time of ventilation the inner air temperature is decreasing on the value of outer one.

Some main results:

Using two open windows, the temperature decreasing is higher, but not twice. Next temperature decreasing is due to added air draught.

The temperature decreasing by tilted window(s) (1 – 2 K) is very small, compared with fully open window (8 – 14 – 17 K).

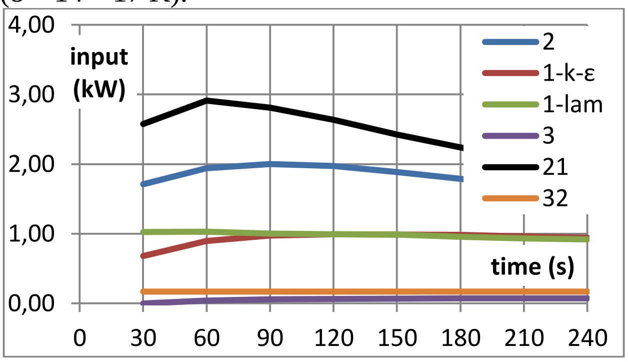

Fig. 15 Heat input for reverse heating

From the value of temperature decreasing it is derived heat input, necessary for reheat of ventilated air in the room on its original temperature and during the same time period as the previous ventilating period – see Fig. 15.
During first 30-60 s after the window opening the flow field is creating and the observed heat input reaches its maximum. Then the value is decreasing.
Of course, the exchange of the polluted air by the fresh one needs some heat input, some operational expenses, too. But the primarily must be always the hygienic point of view and the economic one is the secondary.

The larger is the temperature decreasing, the more intensive is the simulated ventilating process, i.e. the exchange of warm inner air by the cold outer one - see Fig. 16. The value of air exchanges per hour is important parameter for comparison with hygienic directives.
Individual characteristics are similar to the previous graphs.
It is visible that in the first time period the ventilating effect is the biggest. For instance, see the line No. 21: In the moment of 60 seconds of ventilation the immediate air exchange is maximum, 18 per hour, i.e. 0,3 exchange per 60 seconds, i.e. 1 exchange after 200 seconds.
In the moment of 180 seconds of ventilation the immediate air exchange is 14 per hour, i.e. 0,7 exchange per 180 seconds, i.e. 1 exchange after 260 seconds. The temperature of inner air is decreasing during the time of ventilation, therefore the driving pressure gradient (1) is decreasing, too, and the immediate number of air exchanges is decreasing in time.

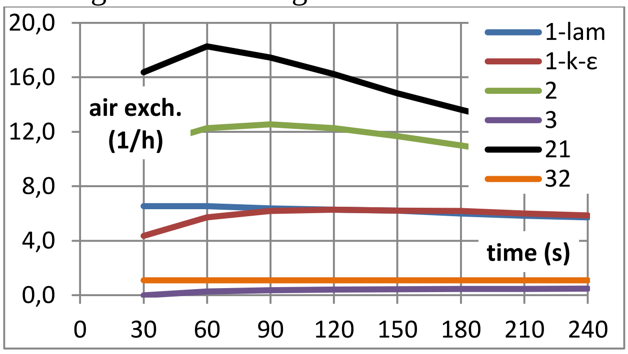

Fig. 16 Air exchange by ventilation

2.6.1 Detailed analysis of thermal flow

In the above presented graphs, there are used average values in the room volume of solved models. Next figures present the flow field in the open window from the Par. 2.3.

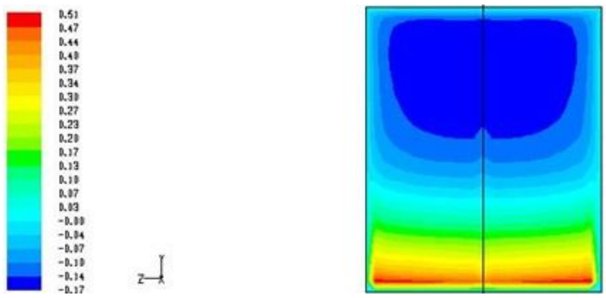
Fig. 17 Velocity field in the open window

The Fig. 17 presents the velocity component through the open window – in the lower part, the air is flowing in (positive value = red), in the upper part, the air is flowing out (negative value = blue).

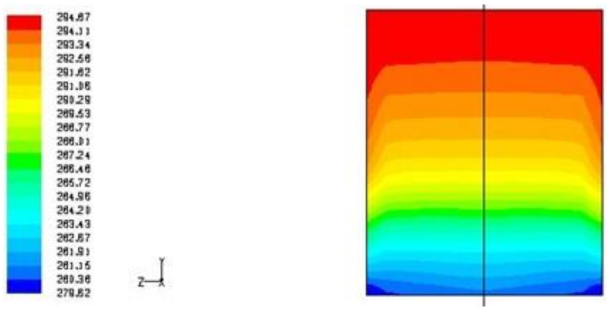
Fig. 18 Temperature field in the open window

The Fig. 18 presents the same situation in the temperature field – the cold air (blue) in the lower part is flowing in, the warm air (red) in the upper part is flowing out.
The Fig. 19 presents the field of turbulent kinetic energy – maximum is in the area of the lower side of the opening where the direction change of the flow along the lower window edge is the highest.

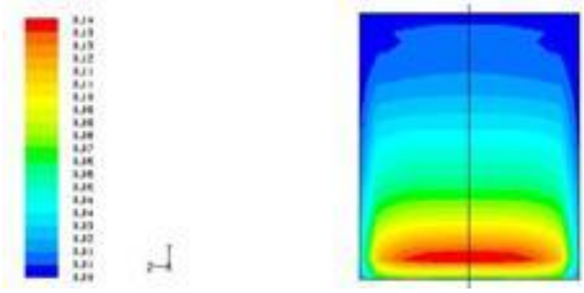
Fig. 19 Turbulent kinetic energy in the open window

From the previous Figures it is evident that the distribution of all parameters of the flow field in the window cross section is considerably uneven. The heat flow balance in the i-th element of the mesh, Fig. 20, is given by the formula (5).

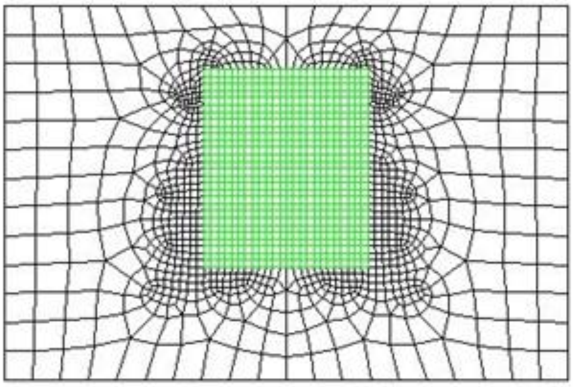

Fig. 20 Example of mesh in open window

Together with (2), (4) the resulting formula is

$$Q_i = p_i / (r \cdot T_i) \cdot S_i \cdot w_{xi} \cdot c_p \cdot (T_i - T_o), \quad (6)$$

where $r = 287{,}1$ J/(kg.K), $c_p = 1005$ J/(kg.K) are material constants of air and parameters "i" are given as result of numerical simulation. The contribution of each such element to the global balance is really given by the sign of the product

$$w_{xi} \cdot (T_i - T_o). \quad (7)$$

They are possible four combinations (+/+, +/-, -/+, -/-), two of them are gains for the observed room, two of them are losses. The value of the function (6) is presented in Fig. 21. It can be said that it is the „product" of Fig. 17 and Fig. 18.

In the lower part, the cold air is flowing in, for the ventilated room it is energy loss, which must be supplied later during reheat. In the upper part, the warmer air is flowing out, but it is usually cooler than the required inner temperature – this cooler item will not cool the inner volume, so it is the relative gain.

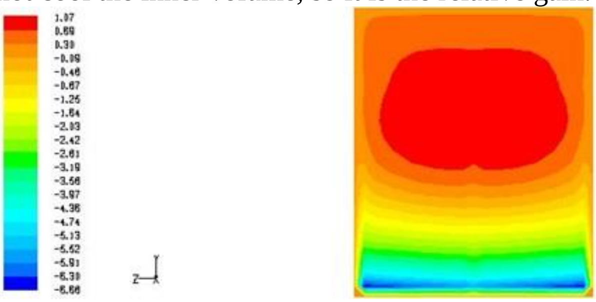

Fig. 21 Elementary heat flows after (7)

3 Forced ventilation

For the same room, it is modelled a forced ventilation as comparison to previous cases, only. Therefore the inlet/outlet orifice is the same as the opening of tilted window from the Par. 2.5, instead natural pressure gradient after (1) here is used artificial pressure gradient of ventilator (6 Pa). Three solved cases observe the influence of the mutual positions of inlet and outlet.

3.1 Outlet close to the inlet (case 42)

Both orifices are situated side-by-side on the upper edge of the window.

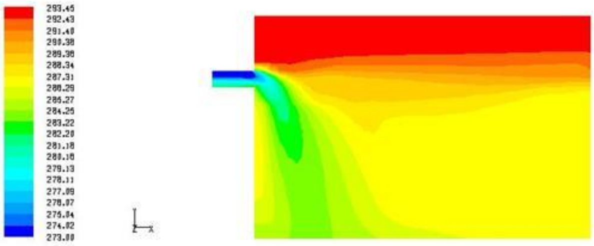

Fig. 22 Temperature field

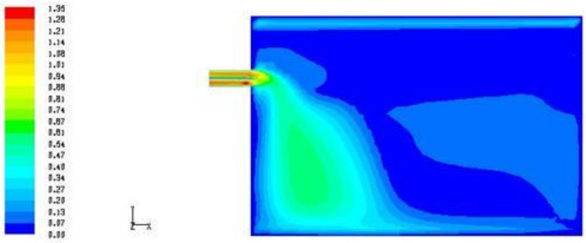

Fig. 23 Velocity field

In both temperature and pressure fields, Fig. 22 and Fig. 23, there it is visible that cold outer air is falling down and in the upper part of the room remains warm inner air. It is not only the result of different air densities (1), but here is affecting also the immediate back suction of some inlet flow into the outlet channel without any ventilation effect in the room.

3.2 Partition between outlet and inlet (case 43)

The previous unsuitable affecting of the inlet flow by outlet flow is suppressed by horizontal partition between inlet and outlet flows, so that the immediate partial back suction of the inlet flow is none. Therefore, the range of the inlet flow and its ventilation effect are stronger, comparing with the previous case, see Fig. 24 and Fig. 25.

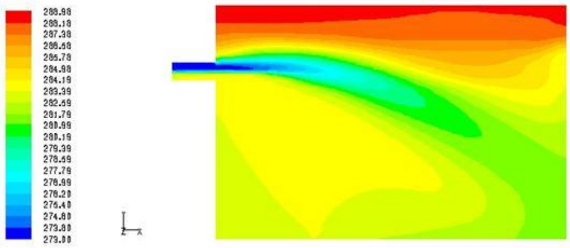

Fig. 24 Temperature field

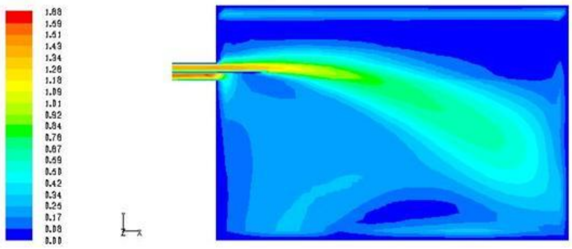

Fig. 25 Velocity field

3.3 Outlet distant from inlet (case 44)

Typically, the inlet is situated in the upper edge of the window frame and the outlet is situated in the lower edge of the window frame. This result – temperature and velocity fields in Fig. 26 and Fig. 27 - is similar to the previous case.

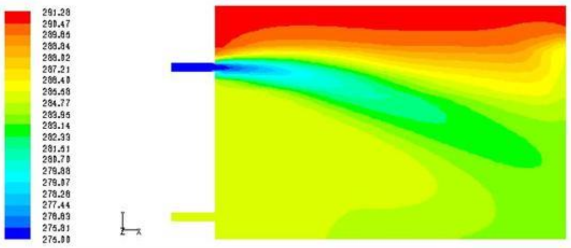

Fig. 26 Temperature field

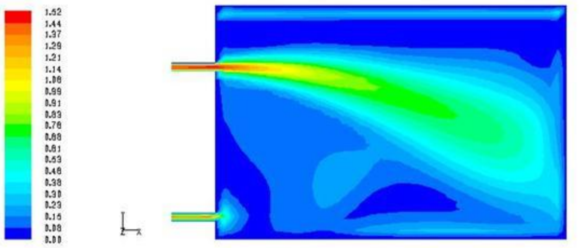

Fig. 27 Velocity field

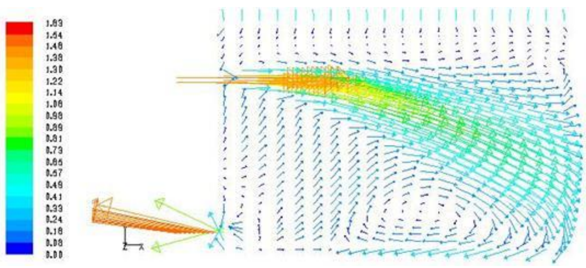

Fig. 28 Directional field

As another view on the results, there is added a directional field in Fig. 28 with large vortex inside.

3.4 Summary graphs

As quantification of the previous qualitative images of the flow fields, here are added graphs of important characteristics of ventilation, similar to the results of the Par. 2.

Of course, the number of air exchanges during the ventilation is here given simply as exchanged volume (m^3/h) divided by room volume (m^3), so any unsteady solution is not necessary here and is used as comparative method, only.

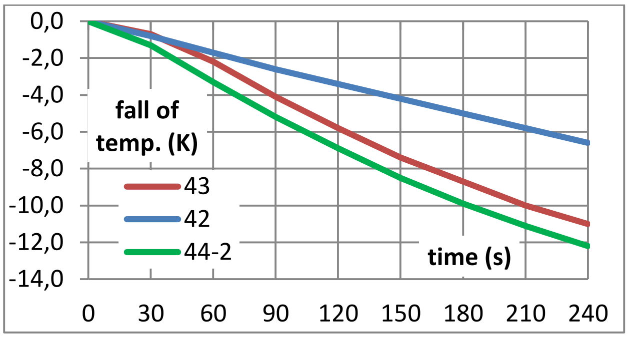

Fig. 29 Temperature decreasing in time

The temperature decreasing inside the room during the ventilation period presents the Fig. 29.

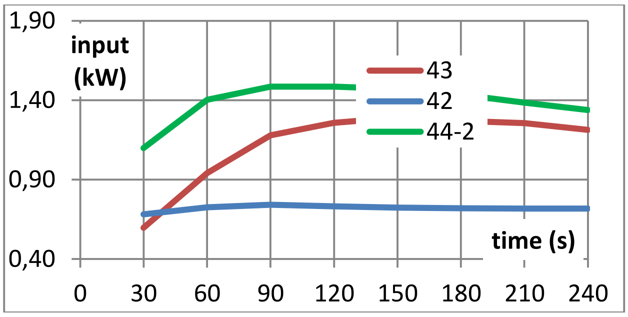

Fig. 30 Needful heat input for reheat of exchanged air

The same situation is represented by graph of heat inputs, needful for reheat of the exchanged inner air, Fig. 30.

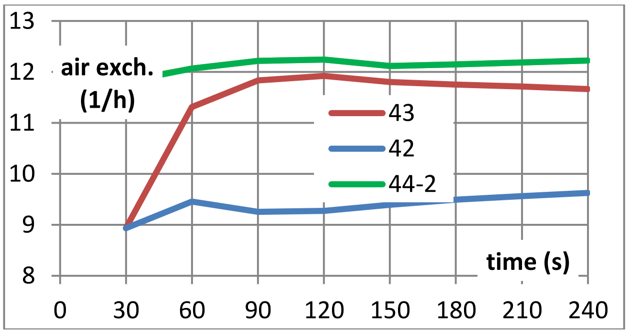

Fig. 31 Number of air exchanges per hour

The number of air exchanges per hour, usually confronted with the hygienic directives, Fig. 31. Comparing with graphs in the Par. 2 here the number of exchanges does not go to zero, but to the value of volume flow (m^3/h) divided by room volume (m^3). Comparing all three solved case, it is possible to state that the case 42 with short-circuit flow between inlet and outlet has the minimal temperature decreasing, i.e. the minimal ventilating effect, too. A separation of inlet and outlet orifices – case 43 by partition and case 44 by distant outlet – gives better ventilating effect.

4 Ventilation by Small Openings

Those cases concern self-regulating window shutters in various arrangements, working under a small pressure difference due to the air draught, wind effect, etc. Simply said, such ventilating gaps (installed in pairs) are used as automatic controlled air exchange at lower driving pressure gradient. When the wind effect is very strong, the flap is shut and the ventilating effect remains limited.

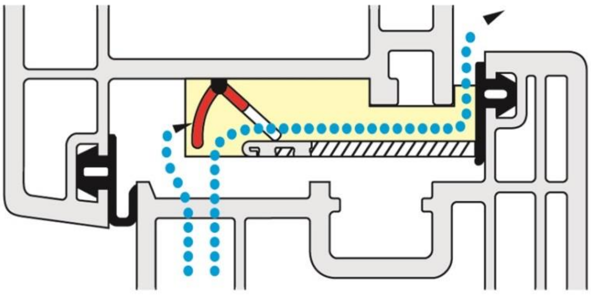

Fig. 32: Ventilating flap in the window frame [7]

The cross section of such a shutter (100x5 mm) is of three orders smaller than the room cross section (4x2.65 m). It is the reason of some difficulties during meshing – in the narrow inlet, the mesh must be fine so that details of the flow field, i.e. flow inlet in the room and its mixing with room volume can be displayed. Therefore, the solution time is increasing. On the other side, in the large room volume, a coarse mesh should be sufficient, but very different dimensions of adjoining elements are the reason of a problem with convergence of the solution.

Therefore, due to a very small cross section of the ventilating gap here it is not monitored the unsteady starting of ventilating process as for the above mentioned large window wing. Here it is supposed a permanent open ventilating gap. The velocity in the room cross section is less than 2 mm/hour so that the flow through the room of 4 m needs over 35 hours. So, this kind of ventilation is absolutely different from the open large window. But for the checking of pollutant exhaust it is sufficient to define the inlet of fresh air (kg/s) and its acceptable saturation by pollutants (heat, humidity, CO_2, etc.). The number of air exchanges is given by the rate of room volume (m^3) and inlet flow (m^3/h), in those cases the value is small but permanent. For simulations was defined the driving pressure difference of 4 Pa (effect of the wind, chimney effect, exhausting etc.).

4.1 Shutters over windows, cross ventilation

Both inlet and outlet are situated over the windows in the opposite walls. In the room volume, there arise two large vortexes, see the field of temperature, velocity and directional field, Fig. 33 to Fig. 35 (marked as case 5). As typical are here two vortexes along the ventilated room.

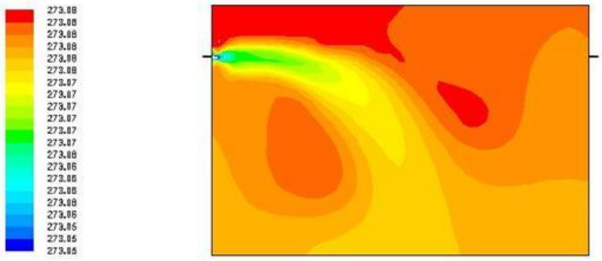

Fig. 33 Temperature field

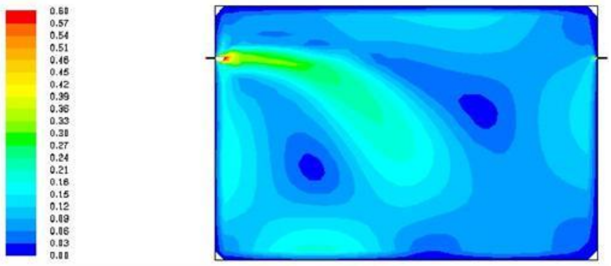

Fig. 34 Velocity field

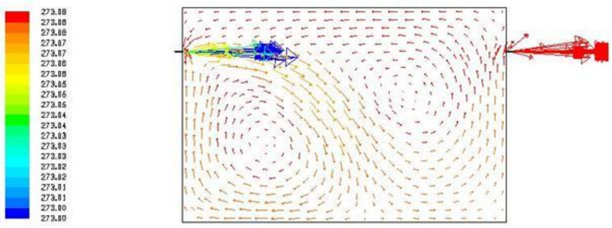

Fig. 35 Directional field

4.2 Exhaust by chimney

This case (marked as case 6) is typical by inlet shutter situated over the window and by outlet situated at the opposite wall at the floor.

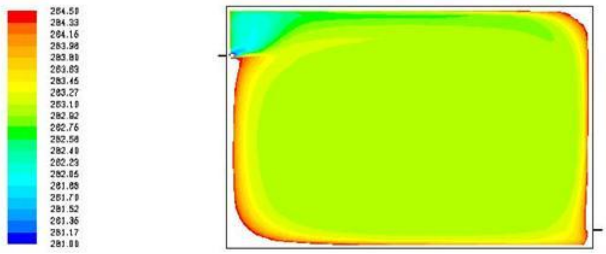

Fig. 36 Temperature field

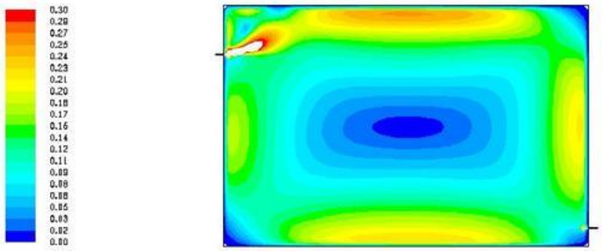

Fig. 37 Velocity field

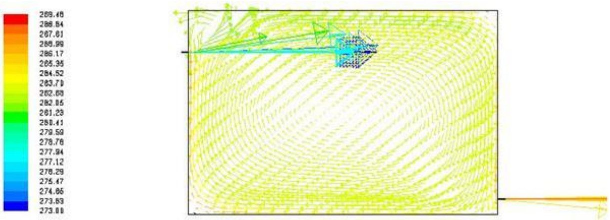

Fig. 38 Directional field

Large vortex along the whole room volume is typical for this case, see the field of temperature, velocity and directional, Fig. 36 to Fig. 38. It is visible the well-known finding that range of the inlet (blown) flow is much more effective than the suction range of exhaust flow of the same intensity.

4.3 Shutters above and below the window

Typical inlet above the window and outlet under the window (marked as case 7). Large vortex in the room volume, see the field of temperature, velocity and directional, Fig. 39 to Fig. 41.

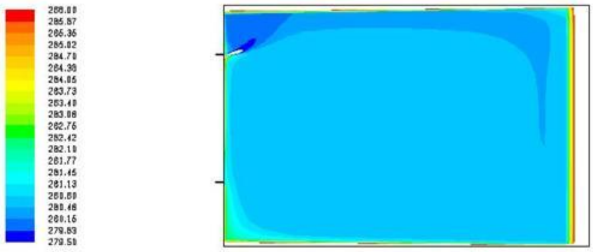

Fig. 39 Temperature field

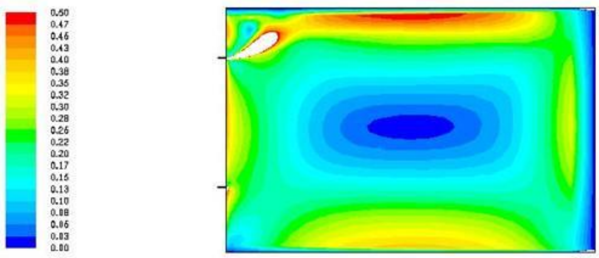

Fig. 40 Velocity field

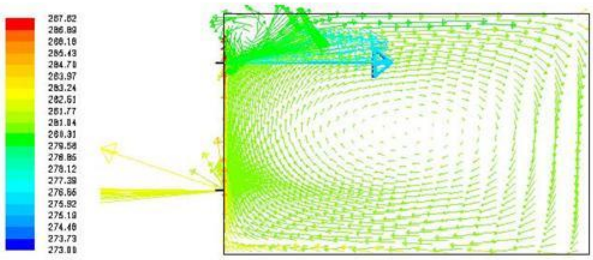

Fig. 41 Directional field

4.4 Exhaust on the opposite side under the window

The image of the flow field for this case (marked as case 8) is very similar to Par. 4.2, see the field of temperature, velocity and directional, Fig. 42 to Fig. 44 below.

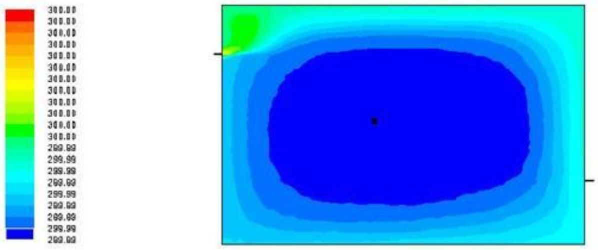

Fig. 42: Temperature field

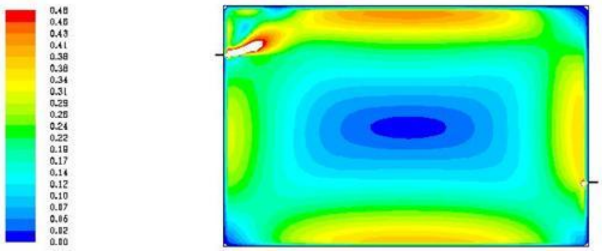

Fig. 43: Velocity field

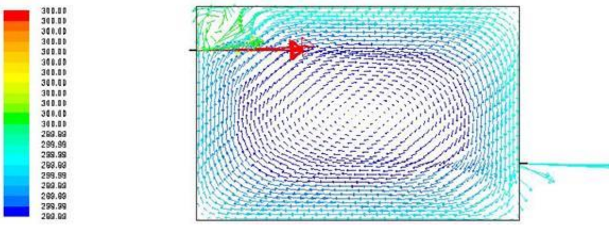

Fig. 44: Directional field

4.5 Added heating unit

This case (marked as case 9) simulates the effect of a heating unit situated under the window (added for the case 4.3). The outlet is separated from the heating unit outlet by a partition to prevent the immediate exhaust of warm air. Instead of a complicated simulation of gravity circulation in the heating unit here it is simply defined

a pressure gradient given by the difference of densities of cold and warm air.
In general, large vortex in the whole room volume is „powered“ not only by gravitational circulation, but by both inlets, too – from outside and from the heating unit, see the field of temperature, velocity and directional, Fig. 45 to Fig. 47 below.

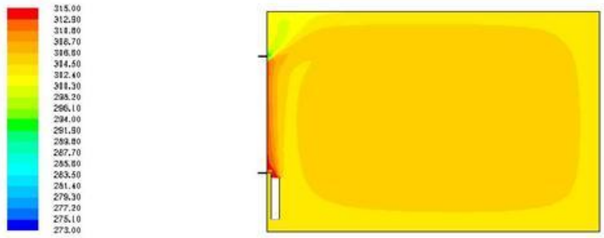

Fig. 45 Temperature field

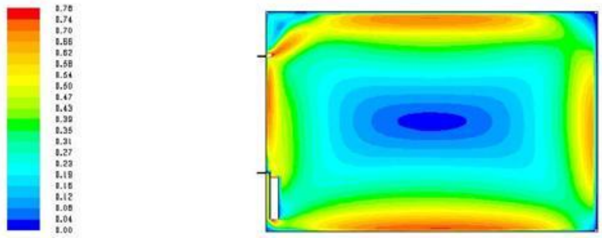

Fig. 46 Velocity field

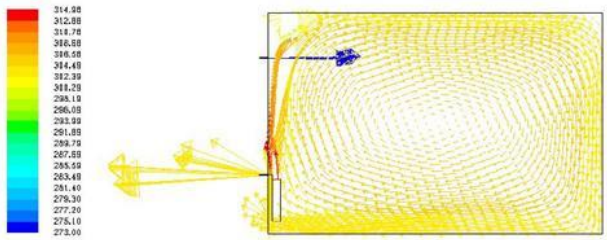

Fig. 47 Directional field

4.6 Summary

The common Tab. 1 summarizes the main results of previous cases 5-6-7-8-9 and gives another view on the results.

case	flow/1 m		flow/red.	exchange
	g/s	m^3/h	m^3/h	1/h
54	19.05	53.2	1.33	0.06
62	15.51	43.3	1.08	0.05
7	27.56	76.9	1.92	0.09
8	23.05	64.3	1.60	0.08
9	20.40	57.0	1.42	0.07

Tab. 1 Main results of ventilation by a narrow gap

The mass flows in g/s of planar simulations (a unitary width of 1 m) are recalculated on m^3/h for the inlet state, then reduced on a real gap width (here 5 mm) and compared with the room volume. The air exchange for individual cases is 0.05 to 0.09 1/h, i.e. one exchange during 20 to 11 hours.
The mutual comparison of individual cases cannot be absolute, the actual air flow or ventilating effect depends on actual setting of other parameters (geometry, initial and boundary conditions).

5 Conclusion

The paper describes several configurations of room ventilation without any energy source, see also another principle [5]. The aim was to compare the effect of individual kinds of ventilation. Presented results of numerical simulations support the idea of environment improvement in living room by simple and cheap natural ventilation, driven by difference between inner and outer temperatures after (1). Like this it is possible to keep healthy environment in living rooms of buildings.
The used geometry is defined as symmetrical to reduce the extent of models. Of course, using, for example, a cross flow, the ventilating effect will be better, but the solution needs a full 3D model. As a standard solution is used unsteady solution.
Short inlets and outlets are modeled, only. Of course, next flow resistances, usually mutually affected, are in relevant longer inlet and outlet ducts. It is not subject of this paper [6]. The image of the received flow field can be affected by next influences, here neglected – walls temperatures (inner, outer, glazing, shady or sunny, etc.), spacious inner items (cabinets, tables etc.), significant heat sources, etc. Such a specific model is much more extensive and needs more time for the model creation, tuning, calculation and results evaluation.
The main results are presented immediately in relevant paragraphs, because supported by images of flow field. For comparison there are added summary graphs of ventilation intensity in time, to compare the number of air exchange per hour with hygienic directives [2].
It proved true that a simple opening of the window wing for short time several times per day can **suppress problems of water vapor condensation** in the cold corners of the room (humidity, moulds), **problems of excessive content of CO_2** (fatigue, headache, decreased attention) and eventually of other present pollutants, without any investment costs. Energy input for reheat of exchanged air volume is not substantial.
Instead periodic window opening the light ventilating flaps, controlled automatically by wind pressure, can be installed [7]. At light breeze the flap is opened, at strong wing is shut again. Practical effect of such devices, applied in windows frames in a real wet

room is presented on the graph Fig. 48 during first three months of experiment [8] – the relative humidity is decreasing and wet walls are subsequently dried. It is the indication that the slight natural ventilation is useful here. The experiment is continuing during all the year round, to take into account the influences of different temperature and humidity of outer air, too.

For old building it is necessary to use any regular ventilation – by short-time window opening several time per day, by additionally installed small artificial leakages, as for instance ventilating flaps etc. New buildings are air-tight and therefore they should be equipped by any kind of air exchange, which ensures the necessary exchange of inner air by the fresh one, together with necessary heat recovery between used and fresh air volumes.

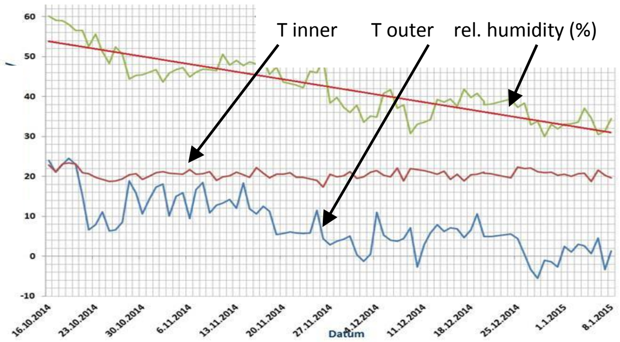

Fig. 48: Relative humidity decreasing due to used ventilation flaps

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