INFLUENCE OF AIR INFILTRATION ON THE ENERGY CONSUMPTION IN THE LARGE INDUSTRIAL HALLS

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Introduction

The air tighthess of the structure is a very important parameter of the large industrial halls energy consumption. Especially serious problem exists during the windy days with low outside air temperature.

The comparison between heat transfer losses and infiltrating air heat demand will be shown in the paper.

The presented computations relating to the typical hall structure are based on the computer programs prepared by the authors.

The Infiltration Effect

General Model

It is assumed that outside or inside air static pressure on the same level is constant. One can distinguish j homogeneous surfaces like slots, cracks, open windows, porous walls etc. in the whole enveloping area of the hall. Each of the surfaces can be divided into elementary horizontal strips of 1 number.

The air mass flow through the elementary strip can be computed from well known equation (1,2,3) valid for steady state conditions:

$$\Delta M_{i,k} = a_i x (p_o - p_i)^{b_i}_{i,k} \times \Delta A_{i,k} \times \rho_{i,k} \qquad (1)$$

where:

ΔM	-	elementary strip air mass flow	kg/s
a,b	-	air transmission factors (1,2,3)	
p_o	-	outside air pressure	Pa
p_i	-	inside air pressure	Pa
ΔA	-	elementary strip surface area	m^2
ρ	-	inside or outside air density on the elementary height	kg/m^3
i,k	-	homogeneous surface and strip indexes	

If the pressure difference is positive, ΔM is positive and called air infiltrating mass flow. If the pressure differece is negative, ΔM is negative and called air exfiltrating mass flow. If the difference is equal 0 there is no air trasmission and the level is called neutral level (valid only for elementary strip).

The outside air pressure p_o corresponding to the height of the elementary strip is computed as an algebraic sum of the static outside air pressure and wind pressure based on the power-low formula wind velocity profile and wind pressure coefficients (1) or from computer air flow program ACFES2/R (4).

The inside air pressure p_i corresponding to the height of the elementary strip is computed from the unknown inside air pressure on the floor level p_x.

The inside air pressure on the floor level p_x can be obtained from the air mass flow equilibrium nonlinear equation as follows:

$$\sum_{i=1}^{i=j}\sum_{k=1}^{k=1} \Delta M_{i,k} + M_{vi} - M_{vo} = 0 \qquad (2)$$

where:

M_{vi} - mechanical inlet ventilation outside air mass flow kg/s

M_{vo} - mechanical outlet ventilation outside air mass flow kg/s

Computer Programs

Infiltration and Heat Transfer Losses

Computer program INFILS prepared in FORTAN IV is based on the 3-D geometry hall enveloping. Generaly geometry data, heat transfer and air transmission coefficients for every surface velocity and wind direction as well as barometric pressure, outside and inside air temperature at the ground level and temperature gradient and mechanical ventilation air mass flow are needed. To solve the nonlinear air mass flow equation (2) numerical methods are using. The heat transfer losses are from the very well known heat transfer steady state conditions equation computed.

Air flow around the Hall

Satelites of the general purpose code ACFES2/R in FORTAN IV are prepared to the local wind pressure coefficients obtaining in the case when the neighbouring buildings exist. Wind pressure coefficients are calculated on a basis of static pressure and velocity fields, the later are evaluated by finite difference procedure applied to incompressible, elliptic Navier-Stokes, continuity and k-ε turbulence model equations. Boundary conditions were as follows:

- fully developed turbulent flow on the windward side, velocity and turbulence parameter profils assumed,
- zero normal gradient on the fictitrous upper boundary, except of vertical velocity component assumed zero value,
- power-low formula, velocity profilce profile near earth and hall surfaces - "wall functions",
- no boundary condition needed for the leeward side (outflow).

Details of the computer code and the numerical procedure may be found in (4).

Results of the Computations

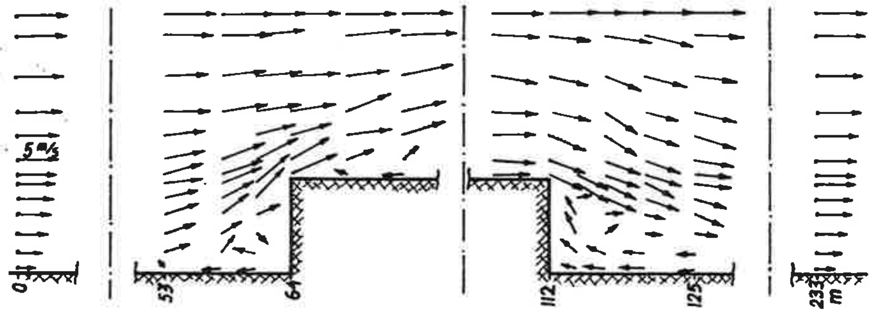
The typical two aisle hall structure was analysed. The dimensions are 74.4 x 48.0 x 7.95 m, two strips of closed windows and two sets of closed gateway in the longer walls. The inside air temperature was 20°C. The 2-D air flow around the building is shown on the Fig. 1. The basic wind velocity was normal to the longer wall and equal 5.0 m/s.

Finite difference grid was of rather coarse type, domain of integration was 23 by 233 mm with 14x30 grid nodes.
Recirculation zones computed are as follows:

- on the windward side origin of the zone is at 0.8 hall height and spreads two heights upwind.
- on the leeward side the wake decays at about 6-7 heights downing.

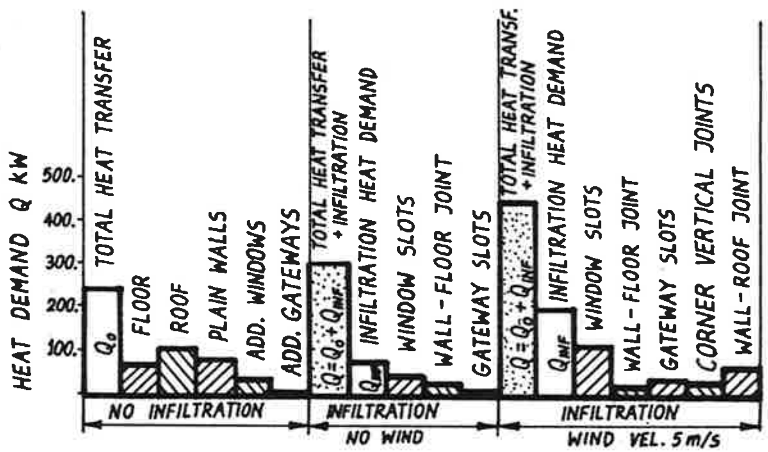
Additional eddy also has been formed along the roof, near the edge of windward wall.

Fig. 1. Air flow around the building, results from ACFES2/R



The heat demand computation results are presented on the Fig. 2. The outside air temperature was -20°C corresponding to winter reference conditions. The overall heat transfer losses was ca. 240 kW, and is called reference heat demand Q_o.

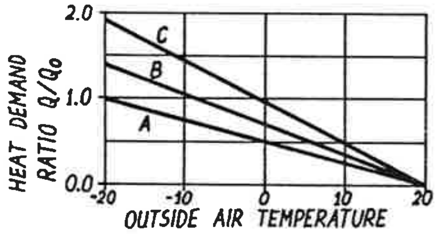
Fig. 2. Overall heat demand for outside air temperature -20°C.



One can observe that the ratio of air infiltration heat demand to heat transfer losses rapidly increases with the air velocity. The most important factor is window and wall-ceiling joints air tightness.

On the Fig. 3 the outside air temperature and velocity influence on the energy consumption is presented. This temperature relation can be in this case linear approximated (small changes of heat transfer coefficients are avoided).

Fig. 3. The outside air temperature and velocity influence on the hall energy consumption.



Conclusions

It is necessary to focus attention on air tightness of the halls structure. The overall heat demand can even be changed very strongly (more than 180% in relation to heat transfer losses) and rapidly. It is caused by the air — infiltration process especially during windy days and is very dangerous because of low heat accumulation of this process.

Those problems should be studied and analysed to define proper methods of designing, building and testing of the structure and heating and ventilation systems. It is also connected with outside air climat investigations, that means it is necessary to obtain statistical correlations and distribution functions for air temperature, wind direction and velocity. The later problem is not solved exactly even in reference year models until now.

References

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SUMMARY

K. Sosnowski, D.M. Lipinski: Influence of Air Infiltration on the Energy Consumption in the large industrial Halls. In the paper the problem of air infiltration effect in large industrial halls is discussed.
Computer programs INFILS and ACFES2/R have been developed for the analysis of industrial buildings heating loads and energy consumption according to air infiltration. The heat demand computations results for typical hall structure are presented. It is shown that on windy days with low outside temperature significant increas in total heat losses exceeded 180%. The necessity of development of proper methods for designing, building and testing elements of industrial buildings and heating and ventilating systems as well is emphasized.

RESUMÉ

K. Sosnowski, D.M. Lipinski: L'influence d'infiltration d'air sur la consommation d'énergie par les grands batiments industriels. Dans ce papier on discute le probleme de l'influence d'infiltration d'air exterieur sur la sonsommation d'energie thermique par les batiments industriels a grandes espaces. On presente les resultats de calculs faits pour la typique construction du batiment. Les calculs sont realises an moyen des programmes INFILS et ACFES2/R pour les compoutears electroniques. On a constate l'accroissement de pertes de chalcur montant jusqu'an 180% de pertes de base, surtont pendant les jours avec la basse temperature d'air exterieur et le vent.
On a constate la necessite d'elaboration de methodes exactes d'establissement de projet methodes, de la construction et de l'attestation de la construction des batiments industriels et des installations de chauffage et de la ventilation.

KURZFASSUNG

K. Sosnowski, D.M. Lipinski: Das Luftinfiltrationeinfluss auf die Energie verbrauch in grossen Industriehallen. Das Problem von Luftinfiltrationseffekt auf die Wärmebedarf von grossen Industriehallen ist erörtert. Die EDV-Programme INFILS and ACFES2/R wurden für die Analyse der Luftinfiltration auf den Wärmebedarf und - verbrauch in Industriehallen entwickelt.
Die Berechnungen für die typische Hallenkonstruktion sind vorgestellt. Man kann zeigen, dass während der windiger Tagen mit niedrigen Aussenlufttemperaturen die totale Wärmeverluste bis zu 180% wachsen könnten.
In dem Aufsatz wurde dieNotwendigkeit für die Entiwicklung von den richtigen Methoden auf der Gebiet der Projektierung, Bauen, Prüfung von Hallenkonstruktion sowie von Heizung und Lüftungssysteme hervorgehoben.