PERFORMANCE OF CURTAIN WALLS FOR PRE-HEATING AIR

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ABSTRACT

For state of the art buildings ventilation heat loss can exceed 50 percent of the total heat loss of the building. Balanced ventilation systems with heat recovery from the exhaust air lead to high costs for ducts. Alternatively, the incoming air of exhaust ventilation systems can be pre-heated by curtain wall facades.

A newly developed simulation program for transient analysis of curtain wall systems is validated by measurements. Parameter studies for pre-heating air with curtain walls are presented. Location, orientation, construction, and geometry are considered. The calculations show that the heat demand for ventilation can be reduced by 50 percent. Efficient systems have a translucent curtain wall and are attached to a thermally insulated wall facing south. Special advice regarding optimal construction is derived from the hydrodynamics of the systems compared. The depth of the air gap can be optimised to values of 2 to 24 mm. The performance of curtain walls for pre-heating incoming air can be estimated over a wide range of parameters.

1. INTRODUCTION

Transmission heat loss of buildings can be easily reduced, even by refurbishing of existing buildings. Ventilation heat loss can be minimised by recovering heat from the exhaust air. Balanced ventilation systems lead to high costs for ducts. Especially, in existing buildings the installation of ventilation systems can induce a high effort. However, if the building envelope is refurbished, the outer layer of the walls can consist of a ventilated curtain wall. This system can be modified to pre-heat the incoming air of an exhaust ventilation system as opposed to a balanced ventilation system with heat recovery.

The function principle of the pre-heating air curtain walls is the following: An exhaust fan depressurizes the ideally airtight room and induces an air flow in the cavity between the curtain wall and the thermally insulated backing wall. The system is built as a duct with an inlet and an outlet. The air is pre-heated by recovering transmission heat loss from the wall by convection in the duct. The primary heat source, however, is the solar energy absorbed in the system. If translucent curtain walls are used, the solar energy is absorbed by a layer covering the thermal insulation (see fig. 1).

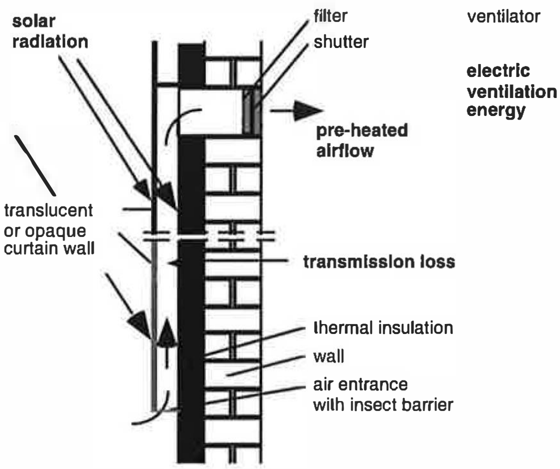

Figure 1: Function principle of the system

The research concept is divided into three parts:

1. A transient simulation program is implemented and used to design the systems in hydrodynamic and thermal aspects.
2. A wide choice of systems are measured on a test cell to validate the simulation program. The overall heat gain is given as reduction of transmission heat loss in comparison with a reference wall area (U-value = 0.39 $W(m^2K)$). Electric ventilation energy demand caused by the pressure drop in the curtain wall system is taken into account. Improved systems which can not be described theoretically are measured simultaneously with systems of equal geometry and predictable performance.
3. Design principles are derived from parameter studies with the validated transient simulation program and practical investigations carried out.

2. SIMULATION PROGRAM

A newly developed transient simulation program describes the complex heat transfer mechanisms under respect of the heat capacity of the wall and the curtain wall. The surface temperatures resulting from this instationary effect are solved with the Crank-Nicholson-Method [1] for finite wall sections in flow direction. The heat convection in the facade duct is described by equation 1 [2]:

$$Nu_x \quad 4.364 + \frac{0.01 \cdot \left(\frac{x}{\mathrm{Re} \cdot \mathrm{Pr} \cdot d_h} \right)^{-1.329}}{1 + 0.0226 \cdot \mathrm{Pr}^{0.155} \cdot \left(\frac{x}{\mathrm{Re} \cdot \mathrm{Pr} \cdot d_h} \right)^{-0.829}} \qquad (1)$$

This equation is valid for thermally non-developed laminar flow in a duct (Re less than 10000). After a length of

$$L_{th} \quad d_h \cdot \mathrm{Re} \cdot \mathrm{Pr} \cdot 0.053 \qquad (2)$$

the air flow is assumed to be thermally developed [2]. In most cases, the height of the discussed air cavity (maximum flow length) is less than L_{th}.

3. MEASUREMENTS

Different systems are measured on a test cell in the city of Kassel, Germany. North and south walls consist of four test areas and a reference area each. The test areas are divided by thermal insulation. Fans induce an air flow through the facade systems. The air is led through ducts equipped with flywheel anemometers for measurement of volumetric flow-rates and is then blown out of the test cell directly. A meteorological station gives 0.1 h mean values for the wind velocity, air temperature and humidity. In the test cell the data acquisition system records solar radiation on vertical surfaces, volumetric flow-rates, ambient air temperatures for orientation north and south, air temperature of the room, and of the pre-heated air flow, and wall surface temperatures (figure 2). A room temperature of 20° C and an air exchange rate of 0.5 1/h representing the inhabitants behaviour are provided. Volumetric flow rate is controlled and the pressure drop in the facade systems is determined. For validation of the simulation program the measured input values for each time step are used.

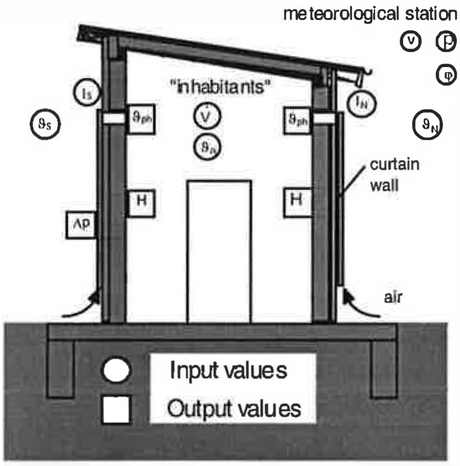

Figure 2: Cross section through test cell

3.1 VALIDATION

Generally, systems with a simple configuration (wall, air gap, curtain wall) can be predicted well by the simulation program. The measured and validated systems are in a range of area from 1.4 m^2 to 5.0 m^2 and depth of air gap between 5 and 50 mm. The system reacts to the solar irradiation and the outside air temperature with increased incoming air temperatures. The calculated incoming air temperatures correspond very well with the measured ones. Differences occur when the solar radiation changes rapidly and at night (influence of longwave radiation to ambient). The calculated heat gains show less than 5 percent deviation from the measured values [3].

3.2 MODIFIED SYSTEMS

Perforated absorber layers lead to a decrease in thermal performance in comparison with simple systems of the same geometry and same physical data (opaque curtain: 15 % less, perforated absorbers with translucent curtain: 0 to 47 % less - for small and large perforations). Using finned (fig. 3) or trapezoidal absorber profiles (perforated or non-perforated) leads to an increase in performance compared to simple systems with the same depth of air gap. Measurements show this increase to be up to 65 %. This performance improvement can be determined in calculation by using the theory for calculating the increase of heat transfer through fins given in [4].

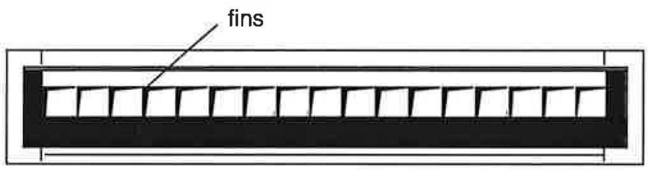

Figure 3: Cross section through a commercial air collector with fins (type: "Grammer" [5])

Best results (+ 89 % as compared to simple system) are obtained by using expanded metal (fig. 4) as heat transfer augmentation device (depth of air cavity = 26 mm).

Measured photovoltaic modules are partially translucent (10 % of solar aperture area) and lead to higher gains as calculated. Furthermore, a rise in the photovoltaic power production of about 10 % is caused by the cooling air (approx. 0.4 %-points increase in efficiency-increment per degree K).

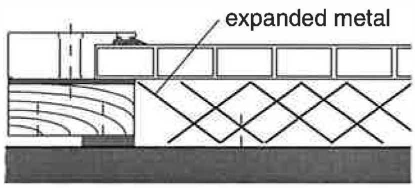

Figure 4: Facade detail with expanded metal

4. DESIGN CRITERIA

The values for heat gains (in comparison with an equally thermally insulated wall) are calculated with the new simulation program using the meteorological data for Würzburg as representative location in Germany. The heating period assumed is from October to April. For parameter variations a system standard is defined. This features a depth of air gap of 0.01 m, a solar aperture area of 2.5 m^2, orientation south, a volumetric flow rate of 75 m^3/h, an U-value of the standard wall of 0.39 $W/(m^2K)$, a transmission grade of the curtain of 0.7 for translucent respectively 0.0 for opaque curtain walls, and an absorption grade of absorption area of 0.97 either for opaque curtain wall or layer on the thermal insulation in case of translucent curtain walls used .

The refurbishing of an outer wall by the application of a curtain wall without thermal insulation is not sufficient despite the fact that the recovering of the transmission loss by systems without thermal insulation is higher than by insulated ones. The reason is that the remaining transmission loss is higher. Non-insulated backing walls lead to thermal problems during summer because the transmission loss becomes negative. Total heat gains of systems with different U-values of the outer wall are shown in fig. 5. Displayed are the heat gains in comparison to the standard wall (U-value = 0.39 $W/(m^2K)$). The influence of the placement of the thermal insulation is nearly negligible. The performance of opaque systems with an U-value of 2.8 $W/(m^2K)$ is equal to the standard wall. Translucent curtain walls lead to more than 4 times higher gains than opaque ones.

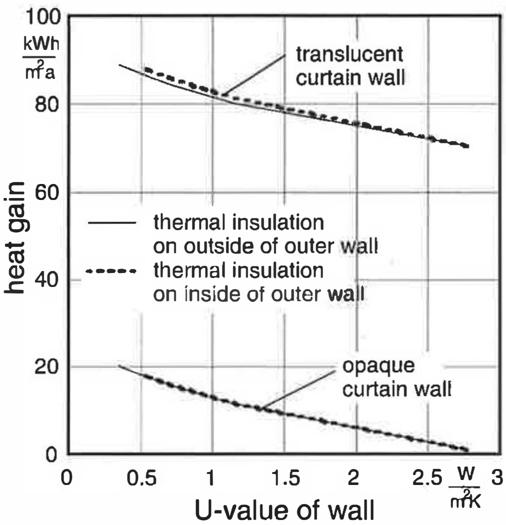

Figure 5: Heat gains of a facade system with translucent or opaque curtain wall mounted on backing wall of varying U-value (in comparison to insulated standard wall) specific to the solar aperture area for heating period (October to April)

The augmentation devices in the ventilated air gap not only cause a rise in heat transfer but an additional pressure loss in the ventilated air cavity. On the other hand, there are an optima of system heat gain for certain geometric constellations displayed in fig. 6 by variation of the depth of the air gap. Electric ventilation energy demand caused by the pressure drop in the facade duct is weighted by a fossil fuel consumption factor for electric energy of 2.5. For different volumetric flow rates the optimised air gap depths are between 0.04 to 0.02 m for a system with 2.5 m^2 solar aperture area. Depths of more than 0.1 m can cause a reduction of heat gains of 50 % compared to the optimum.

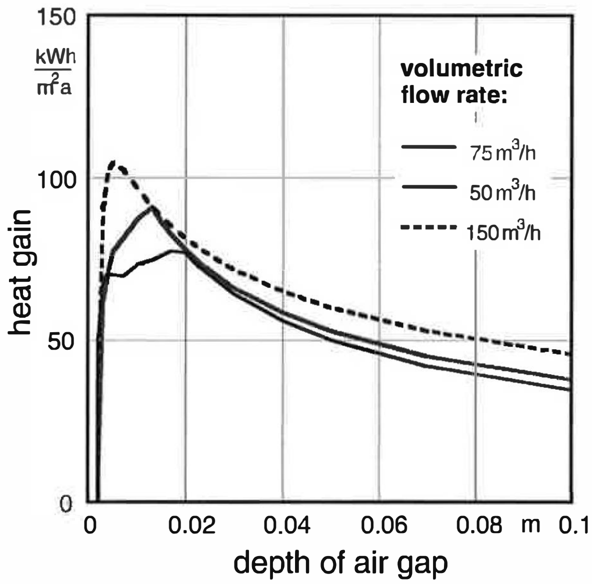

Figure 6: Heat gains of a facade system with translucent curtain wall specific to the solar aperture area for heating period (October to April)

The calculation results for variable solar aperture area presented in fig. 7 show that the efficiency (overall heat gain to solar radiation) of the systems discussed decreases with increasing solar aperture area. The explanation is that the heat transfer coefficient becomes less with decreasing flow velocity, if the area is enlarged by increasing the width of the system. If the area is increased with the height (= flow length) of the system, the mean heat transfer coefficient (eq. 1) is reduced.

An optimisation of the depth of the air gap leads to increased heat gains, e.g., a translucent facade with a solar aperture of 20 m^2 can pre-heat an air flow of 150 m^3/h by 70 $kWh/(m^2a)$ - non-optimised depth of air gap: 49 $kWh/(m^2a)$, see fig. 7. Optimal values for the depth of the air gap are between 2 and 24 mm. To minimise the pressure drop systems should not have a sharp inlet. Large areas and small depths can be provided by using distance holders [8].

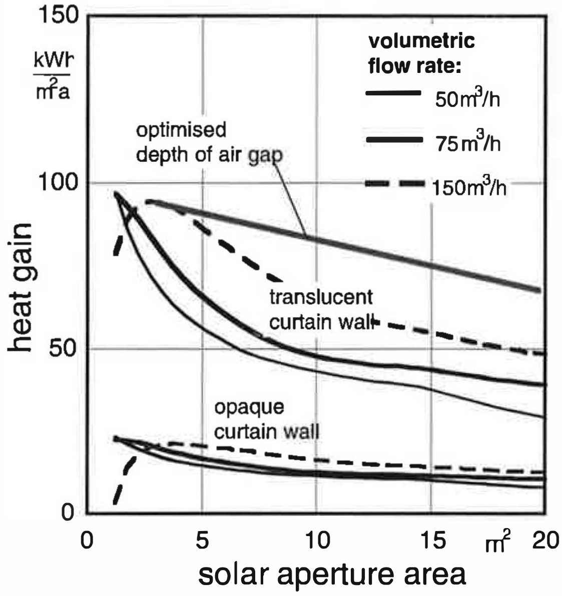

Figure 7: Heat gains of systems with translucent or opaque curtain wall for different volumetric flow rates specific to solar aperture area for heating period

5. COMPARISION WITH CALCULATION METHOD IN PrEN 832 [9]

In prEN 832 [9] a calculation method is given which can be used to calculate solar gains of mechanically ventilated curtain wall systems. The method distinguishes between calculation for opaque and translucent curtain walls. Other input values considered are heat conductance of wall, air gap, and curtain wall, volumetric flow rate and solar aperture area. The method is valid for depths of air gap from 15 to 100 mm, the flow has to be parallel to the wall, and the room is considered to be airtight.

The method misses values or equations for convective heat transfer coefficients and gives no respect to the amount of electric ventilation energy by enlarged pressure loss other than a given minimum depth of the air gap.

Comparisons of own calculations with prEN 832 (mean convective heat transfer coefficient according to eq. 1 assumed) show major differences in the influence of the heat conductance of the curtain wall. In prEN 832 opaque curtain walls with a high heat conductance lead to significantly increased heat gains, translucent curtain walls vice versa. Own calculations show a small influence of this parameter. The orientation of the systems has no influence on performance in prEN 832. The calculation results with the transient simulation program presented in fig. 8 contradict this assumption. The values for solar irradiation on east or west facades for the chosen location are almost equal but the heat gains for west orientation are less than for east. Curtain wall facades facing east have a higher potential for pre-heating air because the system absorbs solar radiation in the early hours when the outside temperature is generally lower than in the afternoon. The heat gains for systems facing south themselves are about 2 times higher than for systems facing north.

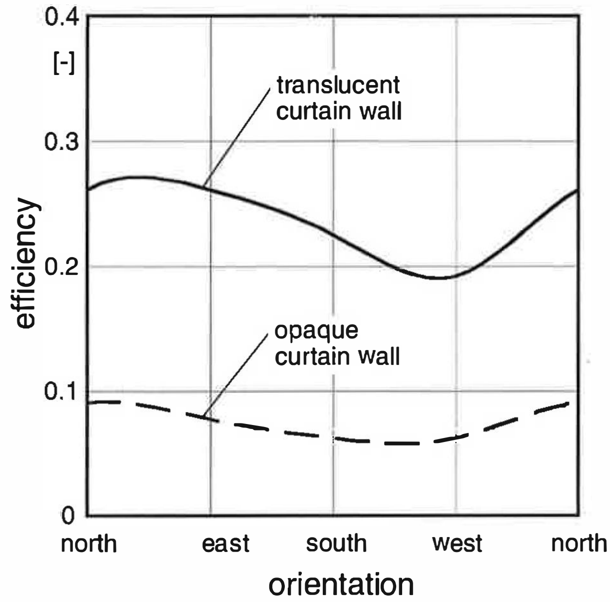

Figure 8: Efficiency of systems with translucent or opaque curtain wall for different orientations

6. SUMMARY

Curtain wall constructions which are used as parts of a ventilation system can reduce the ventilation heat loss of buildings by about 50 percent. Parameter variations with a newly developed and validated transient simulation program show the impact of the primary parameters on the heat gains. Highest gains are obtained with translucent curtain walls mounted on insulated backing walls facing south. Translucent curtain walls lead to heat gains about 4 times higher than opaque curtain walls. The heat gains for facades facing south are 2 times higher than for the same facade facing north.

With increasing area of solar aperture the total heat gain of a system rises, however, the efficiency decreases. By choosing an optimal depth of the air gap (between 2 and 24 mm) the overall heat gains can be increased significantly.

Heat transfer can be augmented by applying expanded metal in the air gap. The cooling of photovoltaic elements used as curtain wall can lead to an increase the photovoltaic performance of 10 percent.

SYMBOLS

Δp	Pa	pressure drop
d	m	diameter
H	kWh	heat loss
I	W/m^2	solar irradiation
L	m	(thermal) developing length
p	Pa	pressure
q	W/m^2	heat flow (specific to area)
ϑ	°C	temperature
v	m/s	wind velocity
$\dot{V}$	m^3/h	volumetric flow rate
x	m	distance from inlet in duct

DIMENSIONLESS CHARACTERISTIC NUMBERS

Nu	Nußelt-number
Pr	Prandtl-number
Re	Reynolds-number

SUBSCRIPTS

a	air
φ	humidity
i	internal
h	hydraulic
N	north
ph	pre-heated
S	south
th	thermal
x	local (in direction of air flow)

REFERENCES

[1] Hauser, G.: Rechnerische Vorherbestimmung des Wärmeverhaltens großer Bauten. Dissertation Universität Stuttgart (1977).

[2] Merker, G.P.: Konvektive Wärmeübertragung, Springer Verlag 1987.

[3] Hauser, G. und Heibel, B.: Zuluftfassaden–Simulationsmodell und meßtechnische Validation. Ges.-Ing. 117 (1996), H. 1, S. 1 - 8.

[4] VDI-Wärmeatlas VDI-Verlag 1984.

[5] Barthel, H.: Solar-Luft-Kollektoren "Neue Möglichkeiten und Lösungen, insbesondere im Verbund mit Gebäude-Lüftungs- und Luftheizanlagen", Vortrag Stadtwerke Kassel 29.10.1992.

[6] Esdorn, H., Fortak, H. und Jahn, A.: Entwicklung von Testreferenzjahren (TRY) für Klimaregionen der Bundesrepublik Deutschland. Statusbericht BMFT. Verlag TÜV Rheinland (1985), S. 424 - 437.

[7] Testreferenzjahre - Meteorologische Grundlagen für technische Simulation von heiz- und raumlufttechnischen Anlagen. BINE, Profi Info-Service (Okt. 1991).

[8] Hauser, G. und Heibel, B.: Bemessungsgrundlagen für Zuluftfassaden, Bauphysik, Heft 2, 1998.

[9] prEN 832: Wärmetechnisches Verhalten von Gebäuden - Berechnung des Heizenergiebedarfs - Wohngebäude, 8. 1997.

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