Doctoral Thesis

Experimental and theoretical studies on the energy balance of windows

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EXPERIMENTAL AND THEORETICAL STUDIES
ON THE
ENERGY BALANCE OF WINDOWS

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SUMMARY

The energy transfer through windows is significant in relation to the energy consumption of buildings. Therefore, we have investigated the energy performance of conventional and advanced multiple-glazed windows. The aim of our study was to gain a detailed knowledge of the physical phenomena controlling the energy transfer through different types of windows. Therefore, we have provided a simple characterization of multiple glazings, which allows us to compare different windows subject to arbitrary environmental conditions and to discuss their energy performance.

In order to judge the energy performance of windows we have measured the spectral transmittance and reflectance of many commercial glazings with two double-beam spectrometers in the wavelength range between 200 nm and 45 µm. From these spectra we have calculated the relevant data of single and multiple glazings with respect to solar and thermal radiation.

In addition, we have performed in-situ measurements on a test cabin at EMPA Dübendorf, Switzerland. This cabin has been equipped with two different windows, a "Float" triple glazing and a "Silverstar" double glazing. We have measured the surface temperature of the individual glass panes with thermocouples and with radiometers. In addition, we have determined ambient air temperatures, global wind speed and direction as well as solar and thermal background radiation. The data have been stored by a personal computer.

Furthermore, we have determined the forced-convective-heat-transfer coefficients of the outside surface of the multiple glazings of our test cabin. We have derived these specific data from additional investigations on the convective-heat loss of the glazings on scaled models of the test cabin in a water channel and in a wind tunnel. Thus, we have demonstrated that the forced-convective-heat-transfer coefficient strongly depends on the wind direction, the location on the building envelope and the shape of the building. We have observed a maximum convective-heat-transfer coefficient when the air flow is turbulent at the windows. However, we have to emphasize that the relation between
this coefficient and the global wind velocity presented in this study is valid only for building shapes corresponding to our test cabin. Therefore, there still exists the need for a general relation which is valid approximately for all building geometries.

Finally, we have designed a theoretical computer model of the energy transfer through fenestrations based on the assumption of steady-state conditions. It includes heat transfer by convection, conduction and radiation and allows us to simulate the performance of windows. We have found excellent agreement between the simulated data of the glass-pane temperatures and the in-situ measured glass temperatures. Nevertheless, it should be noticed, that this model, which is applicable to arbitrary fenestration systems, is restricted to slowly varying environmental conditions.

With the described computer model we have investigated the energy performance, i.e. the U-value, of three selected multiple glazings for a wide range of environmental conditions for missing solar radiation. In these cases we have not found a simple relation between the U-value and the environmental parameters, except for the situation where the outdoor surroundings are at the outdoor-air temperature.

The final investigations on the energy performance which take into account incident solar radiation have resulted in a nearly linear relationship between the intensity of incident solar radiation and the solar-heat gain. Therefore, we have introduced a solar-heat-gain coefficient which in a good approximation is independent of environmental parameters.

Our investigations have demonstrated that low-emissivity coatings applied in double glazings improve significantly the energy performance in the absence of solar radiation. Yet, clear double glazings allow better utilization of solar energy.

In conclusion, we may postulate that only an annual energy analysis with respect to the special requirements of each individual building can take into account in detail energy gains, losses and the wide variation of U-values of fenestrations. The presented computer model can easily be extended to this kind of analysis.