#5391

Comparison of measurements on transparent thermal insulation systems with numerical simulations of building envelopes

E. Boy

Fraunhofer Institute of Building Physics Department of Heat/Climate
(Dir. Prof. Dr.-Ing. habil. K. Gertis)
Nobelstr. 12, D-7000 Stuttgart 80, FRG

ABSTRACT

An existing simulation program has been improved in such a way that it is now possible to analyze the thermal behaviour of transparent insulated building facades. The comparison of numerical calculations performed using this model and of associated experimental investigations shows good agreement concerning the system's thermal behaviour, maximum surface temperatures, and long-term mean values. These calculations are based on the assumption that material properties are known and that multi-dimensional effects caused by cold bridges, frames, fans, etc. are describable with equivalent values of thermal properties. Actually, even minor uncertainties regarding indoor air temperature are liable to reduce the agreement of measured and predicted heat flow densities. As could be verified by error analyses, these variances are however still remaining within the range of measurement accuracy.

Another result of the comparison is that the characteristic heat gains achieved by transparent insulated walls are strongly depending on the seasonal variations in climate. In connection with heat gains through windows and internal heat gains, the temporary gains due to the transparent insulation system are only useable to a certain extent since they are obtained in times when they are not needed, as well. This is the reason why results of calculations performed on wall constructions using ideal boundary conditions are not implicitly transferable to real buildings. With indoor climate conditions, user behaviour, and different thermal zones in buildings varying widely, actually useable gains in buildings are not necessarily predictable from numerical investigations of wall constructions.

INTRODUCTION

The numerical simulation program SUNCODE [1] is a general purpose thermal analysis program for residential buildings. In SUNCODE, the mathematical representation of the building is a thermal network with non-linear temperature dependent controls. The mathematical solution technique uses a combination of forward finite differences, Jacobian iteration and constrained optimization [1]. This program allows not only to conduct an accurate thermal analysis of buildings, rooms and building components, but also to quantify the energy gains of passive solar constructions. Special provisions have been made for the analysis of attached sunspaces and Trombe walls.

The data input used for improving the existing simulation code [1] has been provided from the research and development work carried out within the framework of "LEGIS" [2], a project investigating transparent thermal insulation systems in a series of detailed experimental analyses of test walls, test rooms, and an entire test house.

BRIEF DESCRIPTION OF THE PROGRAM

A thermal model of the building or of building components is created by the program user. Subsequently it is translated into mathematical form by the program. The mathematical equations are then solved repeatedly at time intervals of one hour or less for the period of simulation. The program calculates the dynamic performance of the building or building component in great detail and reports the input quantities of energy and power that the heating and cooling equipment must supply in order to maintain comfort conditions. Effects of long-wave or infrared radiation transfer between surfaces in a room have to be regulated by means of other parameters, for example surface coefficients. Shading of external surfaces and windows is allowed by overhangs und vertical offsets. The program also provides for sidefins and shading caused by faraway objects that obstruct the skyline. Simplifying assumptions and approximations have been made throughout the program, such as one-dimensional heat flow through each part of the building's envelope. Temperature dependence of material properties is described using mean values. Time-dependent parameters or parameter-dependent material properties such as transmissivity of transparent insulation layers are approximated by way of effective mean values. The optical and thermal behaviour of windows and transparent insulations or any layer of partially transparent material could be approximated with a set of different parameters like e.g. U-value of glazing or layer, shading coefficient, extinction coefficient, index of refraction, thickness of layer and number of layers. Time-dependent parameters may also be scheduled to describe additional night insulation or to allow for solar control during the summer. Shading of only direct radiation is possible if the sun is obstructed by the overhang or sidefins. Effects on interior thermal comfort conditions can be studied either without heating and cooling devices or with equipment of specified maximum capacities. Air change rates may be either constant, scheduled or temperature-dependent.

COMPARISON OF MEASUREMENTS WITH NUMERICAL CALCULATIONS

Results of experimental investigations of different transparent insulated test walls [3] have been validated with numerical calculations [4]. Fig. 1 shows the test wall in a schematic presentation and also the approximation accomplished in the calculation model. The individual layers of the transparent insulation system, including frames, are assumed as one equivalent homogeneous layer. Existing multi-dimensional effects have been approximated in one dimension only (see Fig. 2).

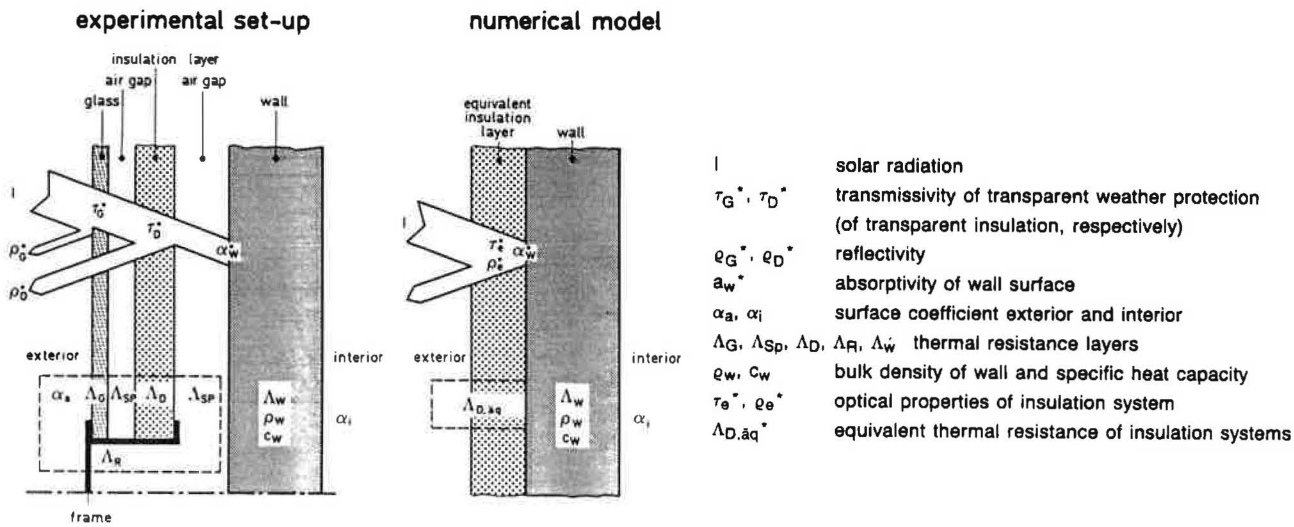

Fig. 1 Schematic presentation of the experimental set-up and of the numerical model

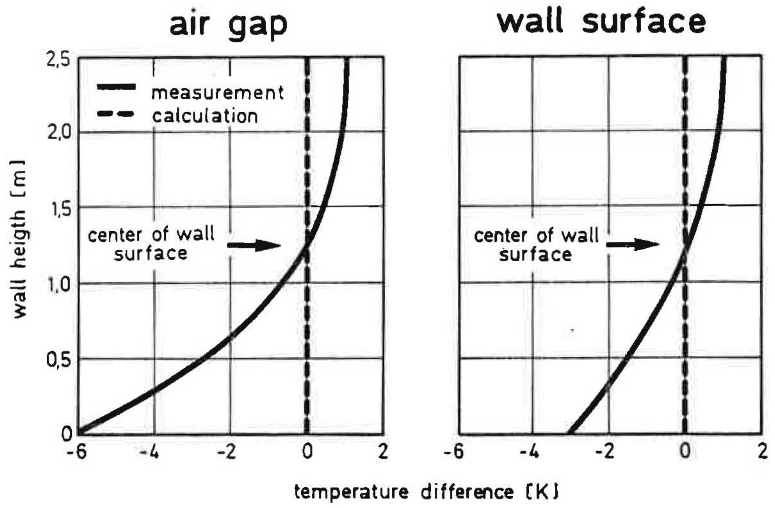

Fig. 2 Multi-dimensional effects measured on a test wall and numerical approximation

The weather data input to the program was supplied by measured hourly mean values of solar radiation and ambient air temperature. Fluctuation of surface coefficients has been neglected. During measurements, the room air temperature was kept constant at 20°C within an absolute accuracy of ± 2 K and a mean accuracy of ± 0.2 K. Fig. 3 shows an example of the results obtained in a six-day comparison of measured and calculated data. Since the program requires unshaded horizontal and direkt normal radiation as data input, there is a minor difference between measured and calculated radiation on the south-facing wall as shown in the top diagram in Fig. 3. The second diagram in Fig. 3 illustrates the fluctuation of outdoor air temperature. These measured data could be used as direct input to the program. The third and fourth diagram present the exterior respectively interior wall surface temperature as measured compared with the calculated fluctuation. Both diagrams show excellent agreement. In the last diagram of Fig. 3 there is a slight difference to be stated between measured and calculated values for heat flux density. Error analysis indicates, however, that within a period of three months an uncertainty of only 0.2 K in temperature measurements eventually results in an uncertainty of more than 2 kWh/m² in heat flux calculation. Table 1 includes the measured and calculated mean values of a three-month period. Again, the results show good agreement between measurement and calculation.

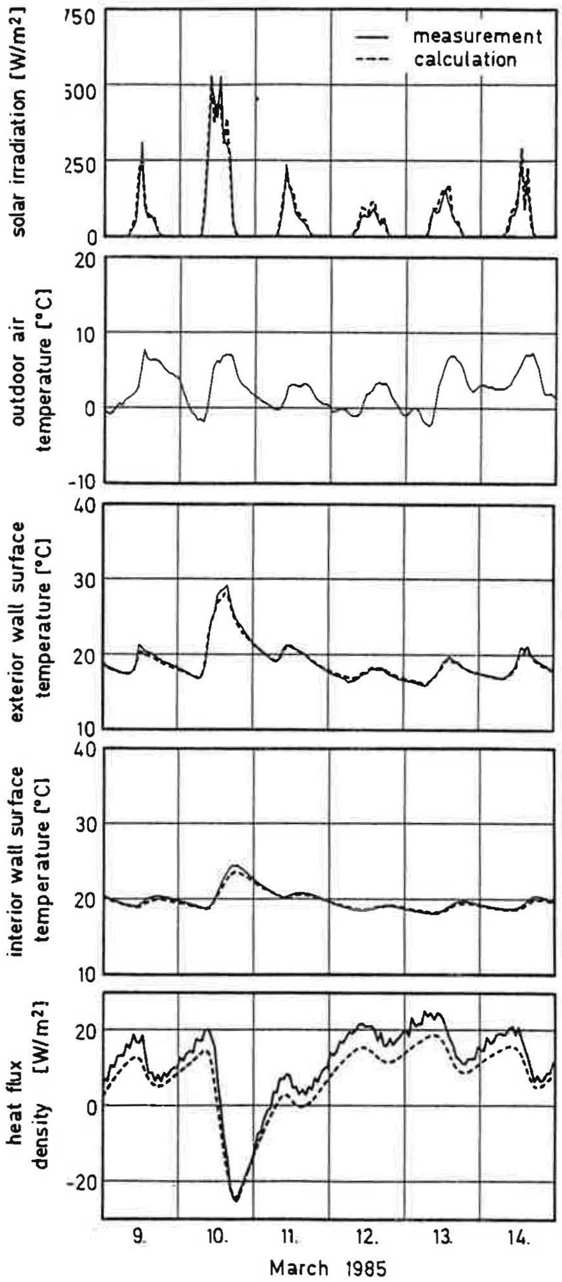

Fig. 3 Six-day example for the comparison of measured and calculated data of a transparent insulated wall

Table 1 Comparison of measured and calculated data (mean values) for a transparent insulated wall over a three-month period

comparison		measurement	calculation	difference	
				absoloute [unit]	relative [%]
solar irradiation [kWh/m2]		130.3	133.3	2.9	2.2
surface of wall [°C]	exterior	22.9	23.1	0.2	0.8
	interior	22.0	22.0	0.0	0
areal heat flux [kWh/m2]	losses	5.40	3.62	1.77*	33
	surplus heat	17.35	19.14	1.78*	10

*An uncertainty of 0.2 K results in an uncertainty of heat flux of more than 2 kWh/m2

Further comparisons of measurement data obtained for one test room and a test house show the same agreement if multi-dimensional effects of material properties are taken into account.

CONCLUSIONS

The comparison of numerical calculations performed using the improved building energy analysis simulation program SUNCODE with associated experimental investigations shows good agreement concerning the system's thermal behaviour, maximum surface temperatures, and long-term values. The calculations are based on specified assumptions and simplifications of system parameters and material properties, which is in fact a result of several years of experience gained in investigating different transparent insulation systems. If material properties are known this improved program allows calculations with an accuracy of $\pm$ 1 K for the thermal behaviour of transparent insulated walls.

REFERENCES

[1] Palmiter, L.; Wheeling, T.: SUNCODE. Ecotope Group, Seattle, WA (1981).

[2] Goetzberger, A.; Gertis, K. et. al.: Transparente Wärmedämmung (Thermal insulation. Final report BMFT 03 E-8414-A.) IRB-Verlag T 1830, Stuttgart (1988).

[3] Lang, H.; Boy, E.; Bertsch, K.; Gertis, K.: Heizenergieeinsparung mit transparenten Wärmedämmschichten an Wandelementen - Meßergebnisse unter idealisierten Randbedingungen -. (Saving heating energy by applying transparent insulating layers to walls - Results of measurements with ideal boundary conditions). IBP-Bericht SA 3/85, Stuttgart (1985).

[4] Schreiber, E.; Heim, U.; Boy, E.: Wärmetechnisches Verhalten transparenter Wärmedämmschichten an Gebäudefassaden - Vergleich Messung/Rechnung (Thermal behaviour of transparent insulation layers applied to exterior walls - Comparison of measured and predicted values). IBP Bericht GB 14/85, Stuttgart (1985).