THE THERMAL ANALYSIS OF LIGHT STEEL-FRAME DWELLING HOUSES

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Received: April 3, 2006

Abstract

Charting the loss of heat due to the heat bridge effect of cold-formed steel sections constituting the load-bearing structure is an important part of the thermal analysis of the building system of light steel-frame dwelling houses. The linear heat transmission coefficient, which serves as a numerical definition of the heat bridge effect, may be calculated on the basis of thermo-photos obtained from in situ thermovisual measurements. The parts of the building under examination have also been modelled through computer simulation, which also provided a value for the linear heat transmission coefficient. The satisfactory coincidence of the results of the two test methods served as a basis of the thermal development of the building system with the aid of simulation models.

Keywords: light steel-frame dwelling houses, heat bridge, thermovisual measurements, computer simulation.

1. Introduction

It was at the beginning of 2004 that Protektorwerk Hungária Kft. approached the Department of Building Construction[1] of BUTE with a request for the comprehensive further development of the Profilház, a widespread building system in the field of light steel-frame dwelling houses. The building system, which structurally consists of cold-formed steel sections assembled on site to provide the loadbearing behaviour of framed buildings, has been analysed from the point of view of building construction, building physics and statics. The results served as a basis of the development. The subject of the present article is reporting on the thermal analysis and the subsequent development.

Proper capability of thermal insulation is one of the qualities associated with light construction dwelling houses. However, it is not easy to characterize that capability. That is because the steel sections forming the load-bearing frame conduct a comparatively greater amount of heat current and thus cause greater heat loss. The thermal insulation layer that fully encompasses the outer surface of the building

[1]The directors of the development: Statics: Dr. Endre Dulácska
Building construction: Dr. Mária Széll
Thermal technology: Dr. János Várfalvi (with the participation of János Várfalvi Jr.
The author participated in the work as an assistant engineer in the framework of her PhD research.

significantly reduces the heat bridge effect. In addition to steel sections geometrical singularities – e.g. wall corners and floor junctions – and the installation of other structures – e.g. doors and windows – also cause heat bridge effect and must therefore be analysed.

The distribution of heat may be represented with the aid of thermovisual measurements and computer simulations as well. The thermovisual measurements performed as part of the expert's opinion of completed buildings coincided with and verified the results of simulation. Thus it was demonstrated that simulation may serve as the basis of the development.

2. Thermovisual Measurements

Thermovisual representation was the first element of the building's physical analysis in the course of site inspections. The device applied was the thermovisual camera, that yielded thermo-physical information. The physical principle behind thermovisual representation is that the amount of energy emitted from the surface of various parts of the building's structure is a function of the temperature of the material. The temperature values of internal surfaces, that are displayed by the software in the form of a coloured picture, may be calculated from the energy emission detected by the camera. The pictures were used in further calculations.

The interpretation of the photos requires the knowledge of the layers of the structure. The layers of the structure in the present case consisted of a vapour barrier and two layers of plasterboard inside, while outside OSB boards, 4 cms of thermal insulation on the entire surface and plastering as external finishing were applied.

The *Fig. 1* picture above leads us to conclusions concerning the quality of the thermal insulation. The most conspicuous feature is the appearance of the lines along the wall columns and the floor beams, i.e. the effect of the steel sections is visible despite the external thermal insulation. On the other hand it is clear from the thermal scale that the differences in temperature compared to a general place are not so significant as in the case of traditional structures (e.g. the heat bridge effect caused by a reinforced concrete ring beam in a brick wall). A greater fall is perceivable in the temperature at the junction of structural elements and geometrically singular points. That is already a different type of heat bridge, which is caused by the superposition of the negative effects of critical parts of the structure. Even there, however, the drop in the temperature is not significant.

It could be observed in some instances during the site inspections that imperfect positioning of the thermal insulation led to a great fall in temperature. That is clearly a result of problems of implementation. Such problems may be prevented by exclusively employing contractors commissioned by the supplier.

In contrast with the heat bridge effect caused by deficiencies of construction the extent of the former kind – the fall in temperature due to structural elements – was generally around Δt=2 K, thus it rather played a part in the energy balance of the building.

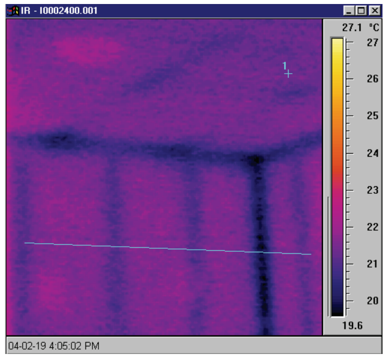

Fig. 1. Thermovisual photograph of the corner of the room [1]

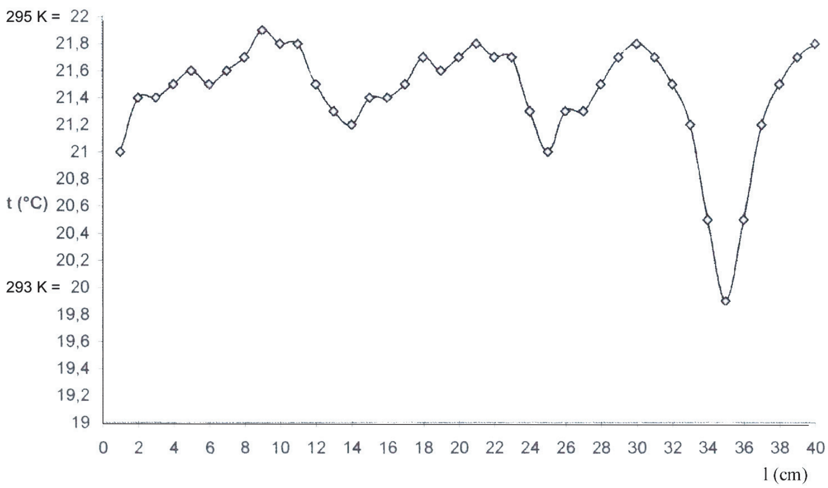

Fig. 2. Representation of the surface temperature of the marked section in *Fig. 1* [1]

3. Linear Heat Transmission

Further calculations are required for the expression of the energetic significance of heat bridges and they may be carried out on the basis of the values represented on the thermo-photos. The effect of heat bridges may be measured through the loss of heat they cause. The linear heat transmission coefficient shows the additional loss of heat through a 1m long section of the heat bridge compared to a part of the structure without heat bridges.

The calculation of the linear heat transmission coefficient begins with the determination of the distribution of heat along a section through the heat bridge and the average temperatures of parts of the structure with and without heat bridge. The heat flux of the typical parts of the structure may be calculated on the basis of the internal temperature and the internal heat-transfer coefficients. The linear heat transmission coefficient is that portion of the difference in the heat flux between parts of the structure with and without heat bridge which is caused by a difference of 1 K between internal and external temperature.

The series of tests mentioned above yielded the following results concerning the section taken through the wall columns and the structure of the corner as shown in *Fig. 1*:

– the linear heat transmission coefficient of the column was 0.052 W/mK
– the linear heat transmission coefficient of the corner was 0.144 W/mK [1].

The value of the linear heat transmission coefficient of other critical points of the building – such as the junction of wall and floor; floor beam; the junction of wall and floor laid on the ground; external corner – may be similarly calculated on the basis of the thermovisual photographs.

4. Computer Simulation

Those parts of the building which have been examined with the aid of thermovision have also been modelled in the form of computer simulation. The significance of simulation lies in the fact that while it is almost impossible to describe such complicated heat processes in a simple form, it facilitates the tracking of two or even three-dimensional heat flux. Each instance of simulation yields a thermocartogram of the structure among specific boundary conditions that is derived by the calculation of a complicated process of heat conduction in a complex construction.

The calculation algorithm of the simulation software is based on the general differential equation of thermal conduction [1, 2].

In the present series of tests a two-dimensional distribution of heat has been simulated. Simulation results came in the form of heat data similar to thermo-photos; linear heat transmission coefficients have to be calculated to facilitate comparison.

The series of tests has been followed up by calculations based on results yielded by simulation and thus the linear heat transmission coefficients of the heat bridges could be determined in all examined parts of the construction.

5. The Comparison of the Results of Thermo-vision and Simulation

The comparison of the results of simulation and thermo-vision is based on the lowest internal surface temperature and the energy transport generated through the heat bridge.

Both test methods support the statement that the temperature measured or calculated on the internal surface of the heat bridges is not low enough to cause any of the problems associated with this phenomenon in practice. On the other hand the relatively high proportion of structural elements means that the decrease in temperature plays a part in the energy balance of the buildings. Thus it is most expedient to focus the comparison of methods on the linear heat transmission coefficient, which is suitable for the representation of that effect.

Thermo-vision was applied in several instances of site inspection and it yielded a set of data concerning (nearly) identical structural details; the average of these results is best used in the comparison. The conspicuously divergent values shall be disregarded in the calculation of the average.

The conclusion may be drawn from the comparative analysis of various structural elements that simulation always yielded a slightly lower value for the linear heat transmission coefficient than thermo-vision. The explanation lies in the idealized nature of the computer model. The deviation of the results of thermo-vision from the average was smaller in the case of simpler structures and greater for more complex structural solutions. (For instance the comparative values for vertical columns were between 0,065 and 0,054 W/mK, and those for an external corner were between 0,150 and 0,136 W/mK.) It was in the latter case as well that the results of simulation deviated more from the measured values.

The values above lead to the conclusion that the calculations based on simulation confirm the results of thermo-visual measurements and that the minor differences between measured and calculated results verify the soundness of the results of simulation.

6. The Application of the Test Results in the Development

Energetic considerations mentioned in the expert's opinions in the field of building construction as well as building physics lay the focus of the development partly on the reduction of the loss of heat (heat bridge effect) caused by the structural elements. Several combinations of layers have been invented to fit the structural system.

Since the construction system being developed has not yet been applied in practice, the heat transmission coefficients of energetic significance may be determined only by simulation and not by thermo-vision. The facts above make it evident, however, that the results yielded by the two test series were sufficiently correlated and thus further simulations serve as proper grounding for various directions of development.

The value of the heat transmission coefficients calculated for the new combinations of layers applied in the constructions being developed significantly improved compared to the old values: a reduction of 13 % was observed for external walls and 15 % for top floor slabs.

The simulation-based linear heat transmission coefficients became comparable to the results of the data of the structural details in the original construction. The values of the tested details deviated considerably from the average but the fact remains that the improvement in this case was more significant than for the heat transmission coefficients of the combination of layers. In other words it became evident that the increasing of the thickness of the external thermal insulation was observable in the improvement of the thermal insulation performance of the structural details as well.

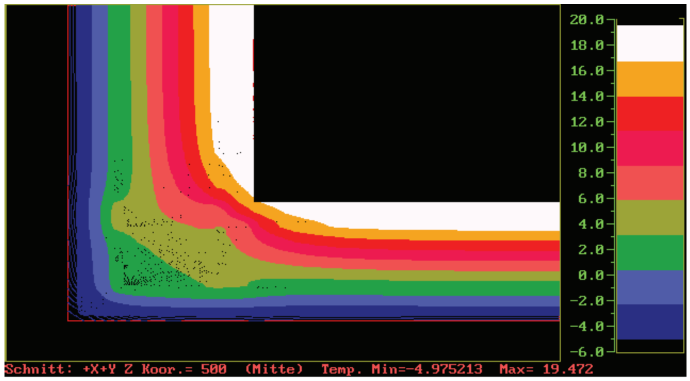

Fig. 3. The simulation-generated isotherms of an external corner with an open air-gap

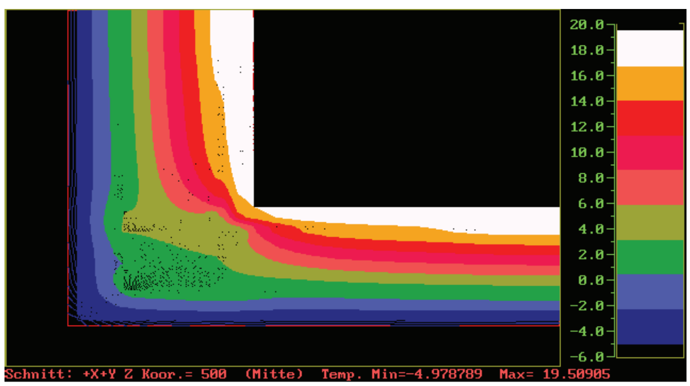

Fig. 4. The simulation-generated isotherms of an external corner with an air-gap filled with thermal insulation. The isotherms are closer to the inner corner than in *Fig. 3*, what is an effect of the thermal insulation.

Numeric simulation facilitates the verification of the efficiency of development. A salient example of that was the case when a structural detail was modelled during the tests and the simulations were carried out for the same structural detail both with an open air-gap and with an air-gap filled with thermal insulation behind the internal covering.

The isotherms of the two-dimensional thermocartogram showed and the calculations verified the beneficial effect of the thermal insulation, the significant improvement of the linear heat transmission coefficient (33% improvement for external corners) in the quasi-critical ranges. The thermocartograms below (*Fig. 3.* and *Fig. 4.*) display the effect of thermal insulation installed in a 40-cm-wide strip on both sides of the corner.

References

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