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Two dimensional FEM analysis - a useful tool in building-physic diagnostic

1. Introduction

In Hungary, most of the damage characterising residential building structures does not stem from structural engineering or quality shortfalls but from building-physics reasons. How could this be, when newly built residential buildings feature lots of intensive heat insulations, high quality masonry units, heat insulated doors and windows? The most frequently occurring moulding and vapour condensation problems indicate that in the designing and dimensioning of 'state-of-the-art' building structures, special care must be exercised.

The question arises why the structural shortfalls leading to these defects are not revealed in the planning stage? This can basically be the result of the following factors:

- An implementation plan document is not drawn up for smaller buildings, and the structural approaches are frequently invented on site;
- The building physics know-how of architects is poor, appropriate operations from a building physics aspect are not considered a priority;
- Innovative but costly thermal bridge breaking structures are not yet sufficiently known and accepted;
- Building physics dimensioning is part of the plan to be submitted for approval, but in practice it is almost only a formality: in most cases only system calculations are made, but the energetics calculation based on a standard does not provide sufficient information either;
- Except for very simple cases, checking the thermal bridges by manual calculation is almost impossible.

In my opinion, a solution is provided by the more frequent use of thermal bridge catalogues or by the **computer analysis of** critical nodes assigned in the planning phase. Easy to handle softwares required for this job have been available for many years, and the dramatic increase in the capacity of computers enables the performing of highly calculation intensive tasks within a short time.

2. Computerised determination of the temperature distribution of building structures

Even with considerable simplifications, determining analytically the temperature distribution of building structures cannot be carried out, therefore we must resort to highly calculation intensive numerical methods. The software (COBIPE, BIDIME, HEAT2) known and used by me in examining transport phenomena apply the method of finite elements or finite differences to resolve the problem.

The basis of these procedures is that the building structure to be examined, or rather one of its expediently selected part, is divided into numerous elementary sub-systems. For each part, the elementary (equilibrium) balance equations can be established with the approximation that within each element the temperature is constant and can be specified by an average figure. These large number of equations make up a huge set of equations, the resolving of which provides the final result. In the course of two-dimensional modelling, the shape of the elements is preferably a triangle or rectangle, and in a three dimensional case a brick-shape is generally involved. When breaking down into finite elements, it is to be ensured that the network is sufficiently 'refined' so that the temperature distribution within each element does not make a decisive influence on the final result, and also that the time devoted to data input and calculation is still acceptable. The shape of elements so assigned must be adjusted to the characteristics and shape of the relevant building structure. It is not advisable, for example, to apply elements with a high ratio between sides. Making the network more dense is advisable in points where a significant change of the temperature can be expected.

The networks may become increasingly larger with the development of simplified 'group type' data input options for programmes and with the increasing capacity of computers. The new programmes can cope with $6x10^6$ elements even in the case of a 3D problem. When checking building structure nodes, in most cases it is sufficient to apply 3,000 to 5,000 elements, because a highly accurate result is not necessary.

After specifying the geometry, the rate of the heat conduction factors λ_{ix}, $\lambda_{iy,}$ λ_{iz} characterising the different sub-elements and elements is to be specified. This raises numerous problems in modelling, because the heat conduction factor rates of construction materials depend on numerous other factors and what is more they are mostly specified in one direction only. The heat conduction factor rates specified in catalogues or standards can be modified with a correction factor $\boldsymbol{\kappa}$ if necessary.

For resolving the differential equation, it is necessary to know the initial and boundary conditions. Selecting and specifying the boundary conditions correctly will make a crucial influence on the results.

The programmes use as inputs the surface heat conduction factors and air temperatures assigned to each edge, but it is also possible to specify the boundary condition of no heat conduction normal to the edge. (The edge so specified can be applied for restricting the task).

Certain programmes are prepared for changing boundary conditions, i.e. transient processes (e.g. the external temperature can be specified in the form of a function). The mathematical problem is even more complicated, if - in the course of determining the temperature range - we intend to take into consideration other interrelations, e.g. the changing heat conduction and heat transfer factors, and only some of the professional programmes are capable of doing so.

The current programmes provide the results not only in the form of a matrix but also graphically, consequently their use is highly descriptive (isothermic lines, colour codes).

2. A brief description of thermal bridges

In the Hungarian design practice, the plan documents submitted for approval include short thermal and vapour technology calculations, serving for checking the sequence of layers applied and also for controlling the energy balance of the building. The validity of layer system calculations is extremely limited, because they assume a constant single dimension heat conduction in the wall structure under the specified dimensioning conditions.

This is because under real conditions, there are *always* parts of the structure along which a single dimension heat conduction cannot be accepted even as an approximative assumption.

Those sites (points, bands and sections) of the limiting structures where as a result of the geometrical conditions and/or the joint use of materials with different types and characteristics two or three dimensional heat flows develop are the thermal bridges.

In winter, the internal surface temperature of thermal bridges may be much lower than that of an average surface. Under certain conditions, vapour condensation and surface wetting may develop on the surface of thermal bridges, and substantial energy may escape through the surface. The low temperature of thermal bridges in certain cases could lead to serious temperature sensation problems, because discomfort zones are generated for example in positive wall corners.

The two basic types of thermal bridges are the geometrical and the structural thermal bridge. The two types frequently occur simultaneously, strengthening each other's effect.

The extent of vapour condensation depends on the surface temperatures, on the temperature and relative vapour content of the air indoors, while the removal of condensation depends on the rate of air exchange provided in the room.

Therefore, in the course of calculations the impact of important sources of moisture in the building must also be taken into consideration. The figures used for guidance in the Hungarian Standard MSZ-04-140/2:1991 show that the moisture load may also be very significant:

Source	***Moisture load***
Moisture emitted by people	*50-250 [g/h/person]*
Having a shower	*2500 [g/h]*
Room plants	*5-15 [g/h/plant]*
Uncovered water surface	*40 [g/h/sq. m]*
4.5kg of clothes being dried	*50-500 [g/h]*

Table 1: Moisture load resulting from using a home

Air temperature t_i [ºC]	*Dew point temperature [ºC] if the relative humidity is*					
	60%	***65%***	***70%***	***75%***	***80%***	***85%***
24	*15.8*	*17.0*	*18.2*	*19.3*	*20.3*	*21.2*
22	*13.9*	*15.2*	*16.3*	*17.4*	*18.4*	*19.4*
20	*12.0*	*13.2*	*14.3*	*15.4*	*16.5*	*17.4*
18	*10.1*	*11.3*	*12.4*	*13.5*	*14.5*	*15.4*
16	*8.2*	*9.4*	*10.5*	*11.5*	*12.5*	*13.4*

Table 2: Correlation among relative humidity, internal air temperature and dew point temperature

When examining thermal bridges, it is a basic requirement to investigate the temperature distribution of the examined structure under the test conditions specified in the relevant country. (According to the Hungarian Standard: t_e= - 5˚C, φ_e= 90%, t_i= +20˚C). The inner surface temperature of thermal bridges must be checked from the aspect of vapour condensation by means of the tables and diagrams shown in the standard.

If the examinations show surface vapour condensation, the most simple way of protection is using thermal technology means, By improving heat insulation, the inner surface temperature of a thermal bridge can be raised.

We can find that today there are many more building physics type of problems than 100 years ago. The reasons for the proliferation of these problems and for an increased awareness about thermal bridges are the following:

- A wide use of well sealed windows – leading to insufficient ventilation;
- The application of high heat insulating capacity, low weight masonry;
- Insufficient heating and ventilation due to 'energy saving efforts';
- The application of internal coatings susceptible to moulding;
- A wide ranging use of reinforced concrete brackets, pillars and attics;
- Designing heavily divided façades and floor plans;
- The construction of dwellings characterised by a small ground space and low headroom.

When examining an existing structure, results can be achieved by a thermovision camera or by computer modelling. (When using the computerised modelling of an existing structure, the risk prevails that the structure has been made by deviating from the plan, therefore the applied sequence of layers and the material qualities must be checked also by exploration if possible.)

3. Some simple case studies:

3.1. Heat insulated reinforced concrete skeleton and brick block packwall

Fig. 3 shows a frequently applied building structure approach. The structural thermal bridge (pillar) is aligned with the geometrical thermal bridge. The computerised analysis shows very clearly that the generally used 5cm thick polystyrene board heat insulation curtain is not sufficient, because these two types of thermal bridge effects strengthen each other. Under the test conditions defined by the standard, the lowest internal surface temperature (12.44 ºC) is below the dew point temperature, consequently in the case of vapour condensation and unfavourable conditions (e.g. higher vapour content, insufficient exchange of air) a moulding is to be expected.

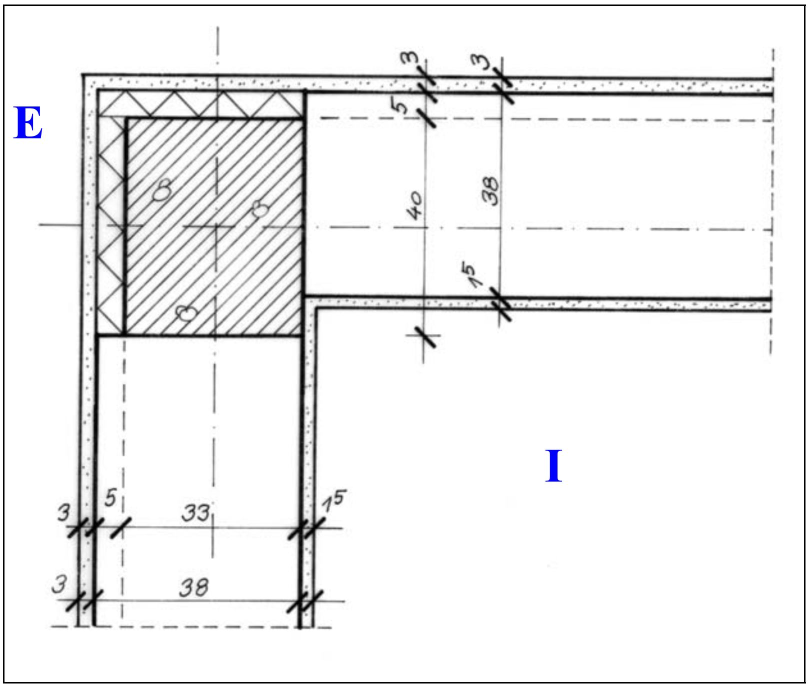
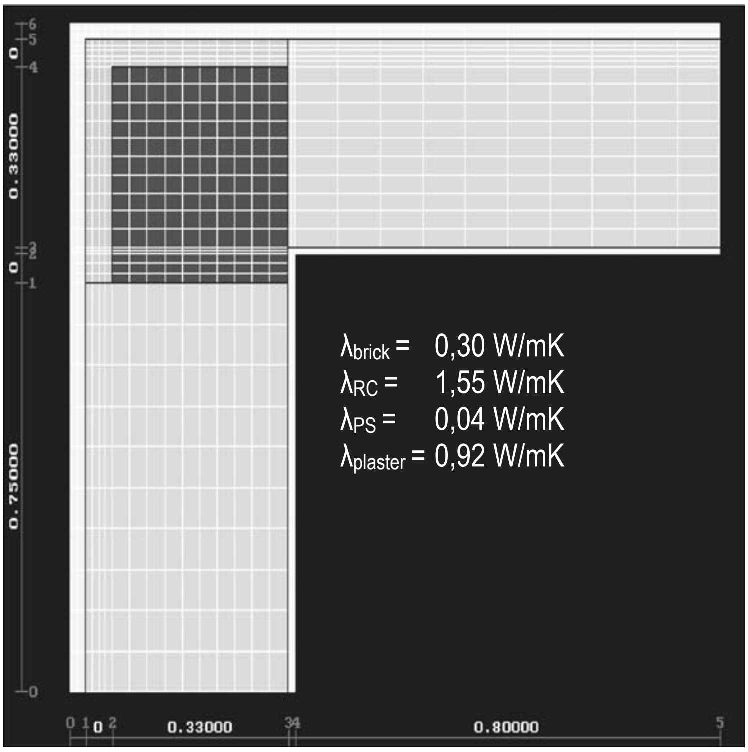


Fig. 1: Corner node design of a skeleton building



λ_{brick} = 0,30 W/mK

λ_{RC} = 1,55 W/mK

λ_{PS} = 0,04 W/mK

$\lambda_{plaster}$ = 0,92 W/mK

Fig. 2: Finite element model of the corner node of a skeleton building. Smaller elements are used in the heat insulation bands.

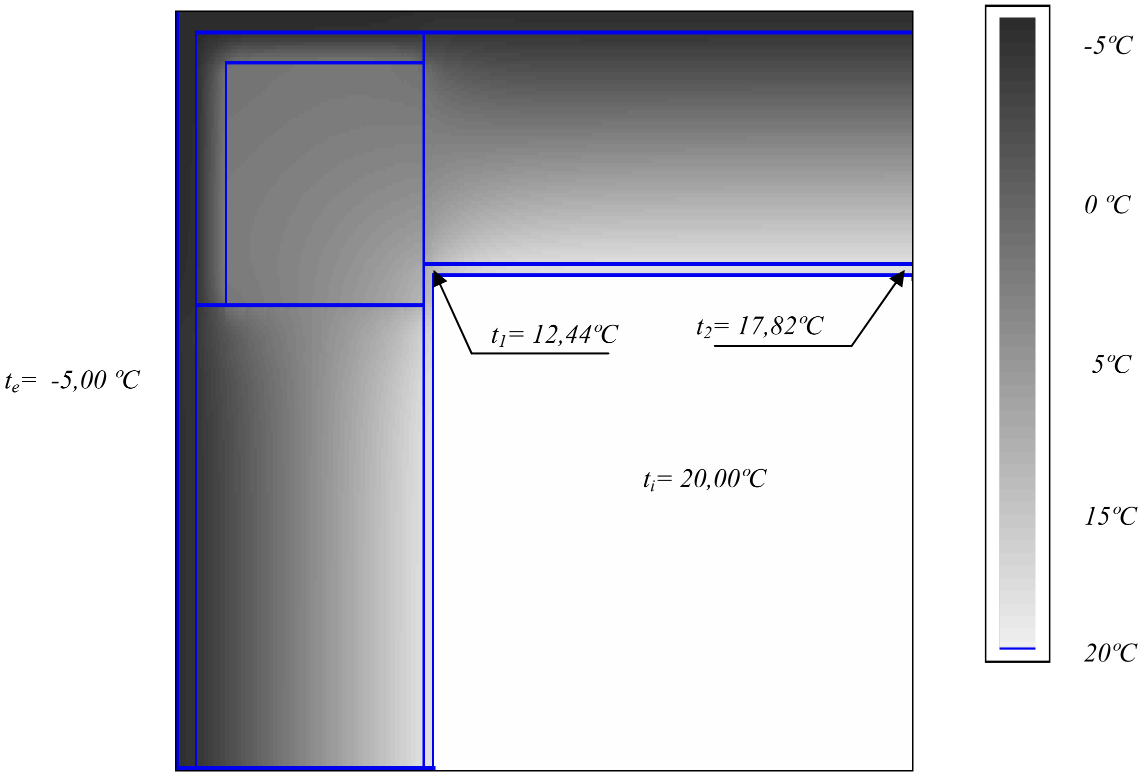


Fig. 3: Temperature distribution of a corner node point of a skeleton building. The surface temperature of the inner side of the pillar is extremely low! Vapour is condensed there. The general surface temperature of the packwall is satisfactory.

3.2. Examining a balcony node

Fig. 4 again shows a frequently applied structure. All experience shows that the structure so developed can be mostly used without a problem, but at other places intensive moulding arises. When studying the computerised temperature distribution, it becomes evident that the lowest temperature (14.29 ºC) on the inner side is very close to the dew point and therefore when unfavourable conditions prevail a defect difficult to remedy will develop. The real solution would be the correct selection of the structure because prefabricated thermal bridge breaking elements are available, and when these are applied even the lowest internal surface temperature can be kept above 16ºC even under the dimensioning conditions specified in the standard. However, the experience is that in the implementation of residential buildings the cheaper but more risky solution is applied.

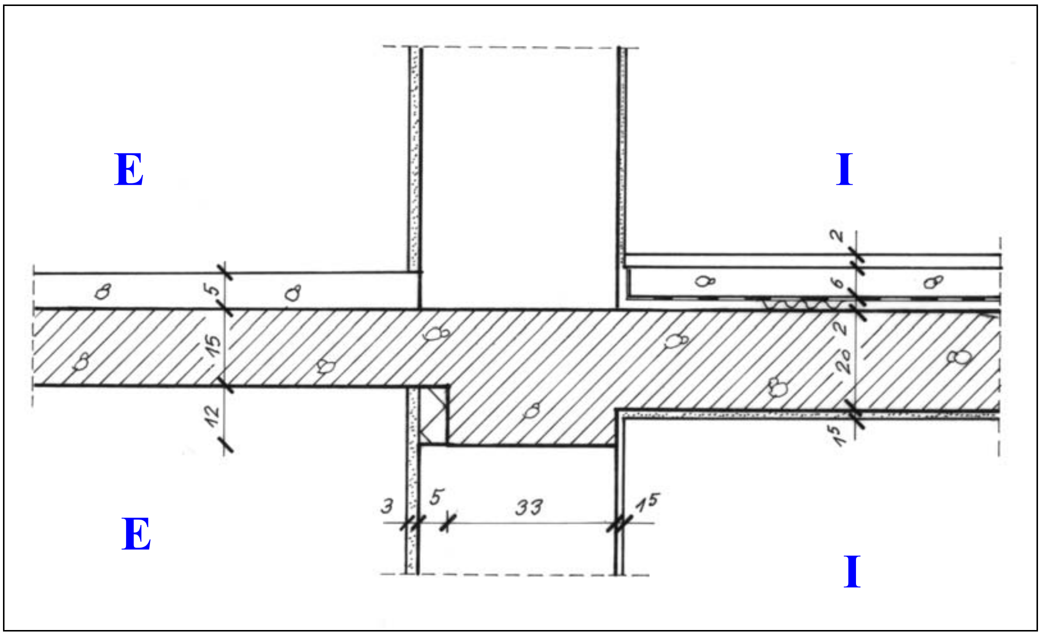


Fig. 4: Designing a bracket balcony slab integrated with the floor, in a brick block wall

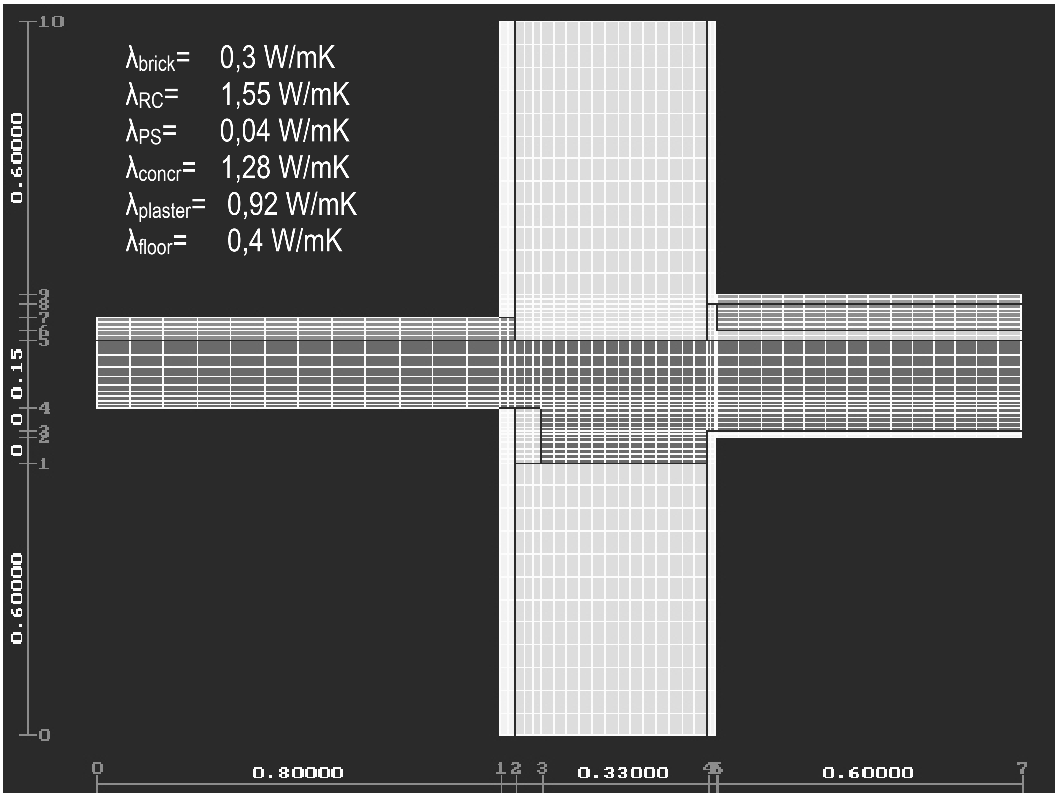


Fig. 5 Computerised model of a bracket balcony slab integrated with the floor

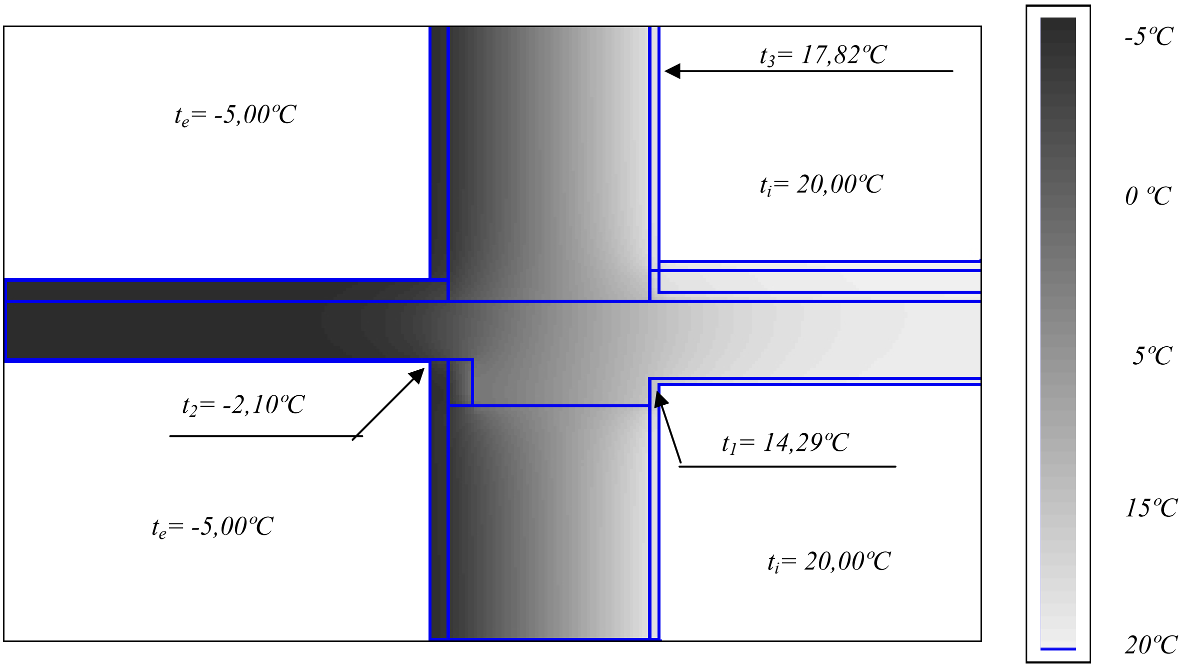


Fig. 6: Temperature distribution in the case of a bracket balcony slab integrated with the floor and brick block wall structure

Note:

I had the possibility to conduct an interesting comparison under laboratory test conditions. A wall structure with thermal bridge fitted into an experimental thermal chamber was equipped with heat detector thermocouples. After heating up the thermal chamber and once the stationary heat flow has developed, the data logging equipment has carried out a number of readings at the different points.

The results were well in agreement with those of the two dimensional calculation.

4. Summary

There are significant differences among the graphic surface and services of the various programmes and the complexity of processing. In the case of product development and research, three dimensional programme systems may also be required, but on the basis of the examples above more simple two dimensional programmes are sufficient, **in fact they are more advantageous for the design engineers.** The uncertainty stemming from the 2D test can be reduced by generating some 'safety reserve'. The resource requirement of the software used for the tests above is minimal, and its size is not larger than the capacity of a 1.44 floppy – therefore there is no explanation why such programmes have proliferated in a limited way and why they are sold at such a high price.