

THERMAL ANALYSIS OF 3-DIMENSIONAL HEAT BRIDGES INCLUDED IN STEEL FRAMED HOUSES - METHOD OF MAKING MODELS AND ANALYSIS EXAMPLES -

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ABSTRACT

In this report, recently developed computer program named TB3D/FDM (Thermal Bridge Computation by 2- or 3-Dimensional Finite Difference Method) is introduced. This program enables steady state heat transfer analysis of building exterior walls including thermal bridges. TB3D/FDM has a tool forming input data set for 3-D computations from DXF file, and employs TRAC3D (Thermal Radiation and Air-Convection in 3-Dimensional Air Cavity) computing thermal resistance of 3-D air cavities. Application process of TB3D/FDM is described, and calculation examples of temperature distribution and condensation risk judgment are shown.

INTRODUCTION

Along with the advancement of energy conservation requirement, thermal insulation of buildings becomes more and more important. In Japan Guidelines of the energy conservation and methods of calculation for the building¹⁾, the overall thermal transmittance was introduced to numerically assess building thermal performance, and the effect of 2-dimensional heat flow must be taken into account to calculate the overall thermal transmittance of exterior walls including thermal bridges.

However, it is impossible for 2-dimensional calculation to properly evaluate the heat transfer at the parts where 3-dimensional thermal bridges exist, such as steel members of a balcony penetrating insulation materials inside an exterior wall. In these cases, it is necessary to evaluate 3-dimensional heat flow. Especially, in order to prevent wall internal condensation.

In the meantime, the performance of personal computers is remarkably improved. This enables designers to use various simulation programs during their design process. Engineers who design insulated windows or doors are requested thermal analysis before mass production stage. Thus, computer programs of 2 and 3-dimensional thermal transfer analysis have been required by these designers and engineers.

The authors have already developed thermal bridge calculation program named TB1 (Thermal Bridge Computation Program Version 1)^{2,3)} which

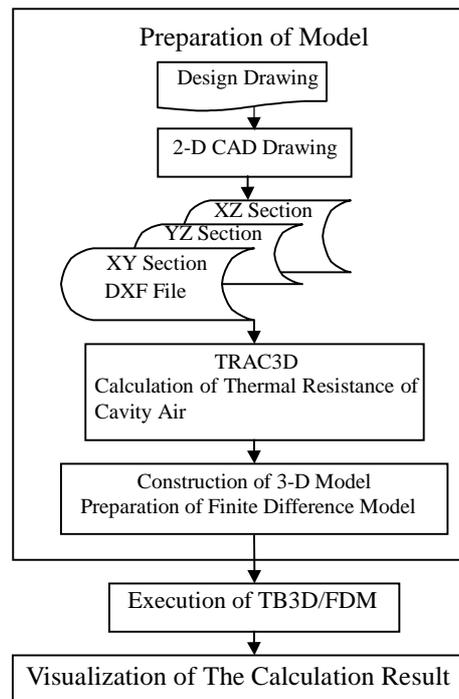


Fig.1. Flow of the computation process.

can compute 2-dimensional overall thermal transmittance. TB1 is available from Institute for Building Energy Conservation (IBEC) of Japan. Recently, the authors have developed thermal transfer simulation programs TB2D/BEM (Thermal Bridge Computation by Boundary Element Method) and TB2D/FDM, TB3D/FDM (Thermal Bridge Computation by 2- or 3-Dimensional Finite Difference Method)^{4,5,6)}. Currently, the trial editions of these programs are completed.

In this report, examples of thermal behavior analysis by TB3D/FDM are introduced. The analyzed subjects are thermal bridges in a typical steel framed house. The modeling process and calculation results are illustrated.

OUTLINE OF TB3D/FDM

TB3D/FDM is a 3-dimensional thermal transfer calculation program on the basis of the finite difference method under steady-state condition. Advantages of TB3D/FDM is the 3-dimensional heat transfer analysis can simulate for a thermal bridges which constructed with a very thin and slender materi-

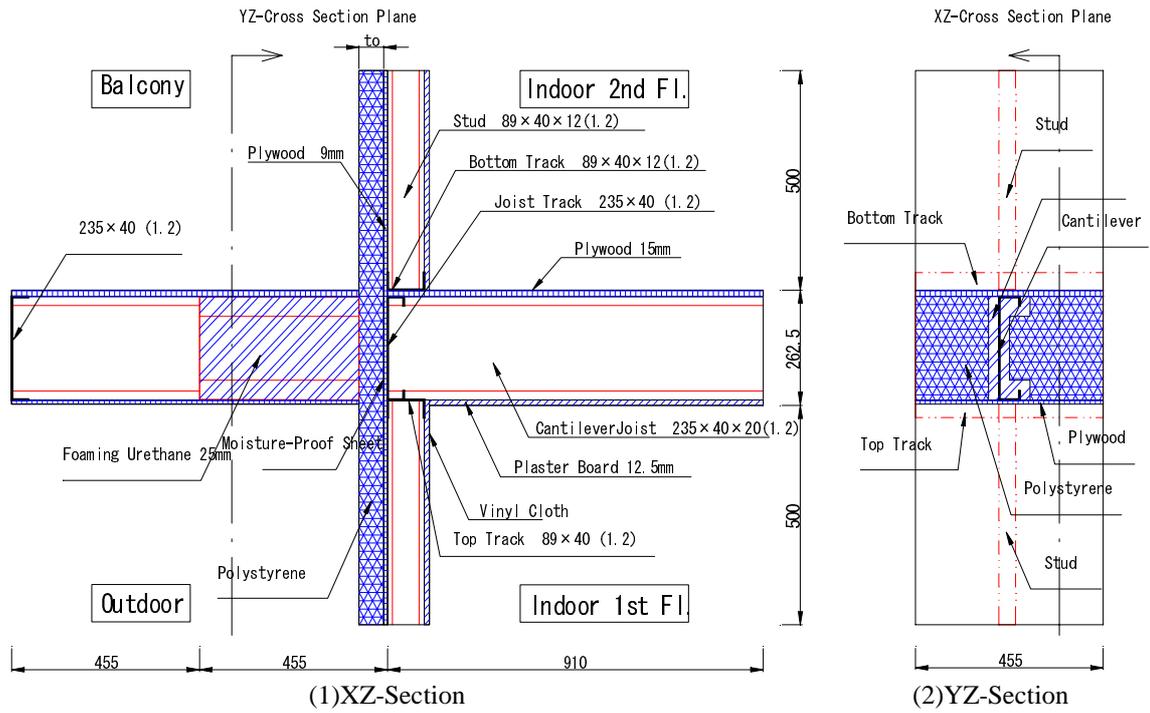


Fig.2. Details of a joint part of a balcony and an exterior wall on steel framed house.

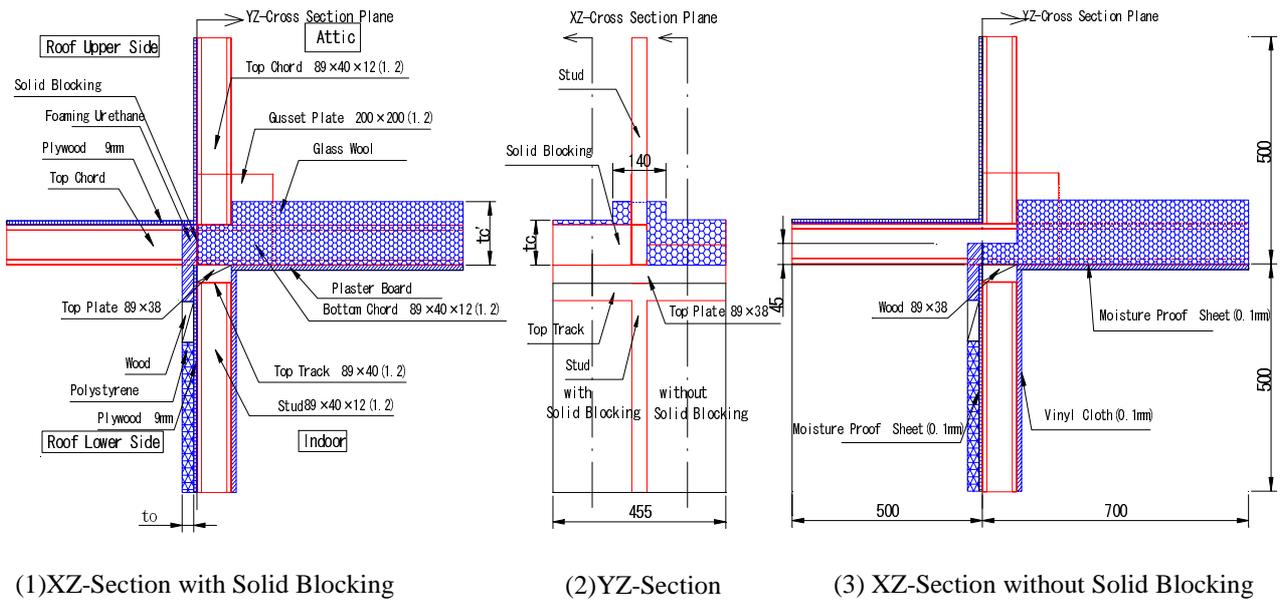


Fig.3. Details of a joint part of a roof and an exterior wall on steel framed house.

als(such as steel or aluminum) or air spaces of various shape and thickness. In this program, an air cavity in a building component is treated as a solid material which has the same thermal resistance with that of the air cavity. A computer program named TRAC3D (Thermal Radiation and Air-Convection in 3-Dimensional Air Cavity) is used for the calculation of thermal resistance of air cavities. It was confirmed that the calculations by TB3D/FDM satisfied the allowable error of temperature and heat flow of

ISO/DIS 10211⁷⁾ models.

OUTLINE OF CALCULATUION PROCEDURE

Flow chart for 3-dimensional heat transfer analysis using TB3D/FDM is shown in Fig.1. The process is divided into 3 parts; finite difference data forming process (pre-process), calculation process, and results visualization process (post-process).

Usually, it requires much time and labor to make

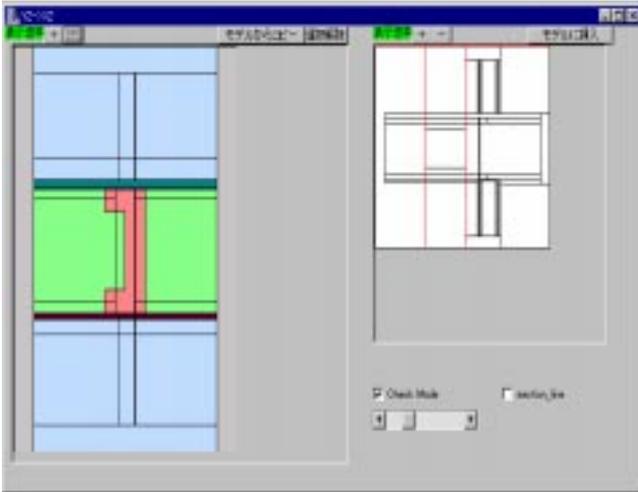


Fig.6. Display screen under confirming a cross section of a balcony and an external wall.

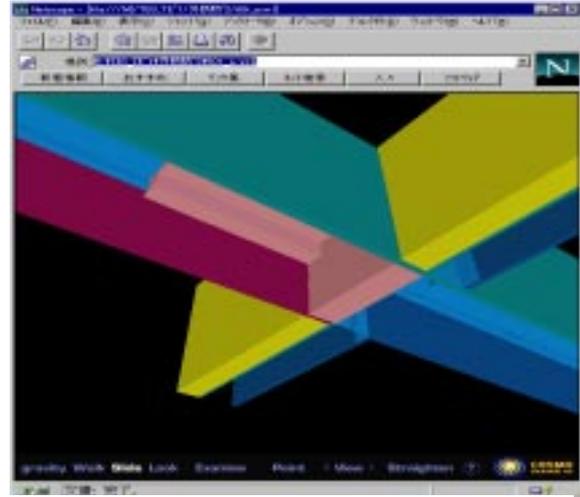


Fig.7. Display screen under confirming the 3-D model by VRML browser.

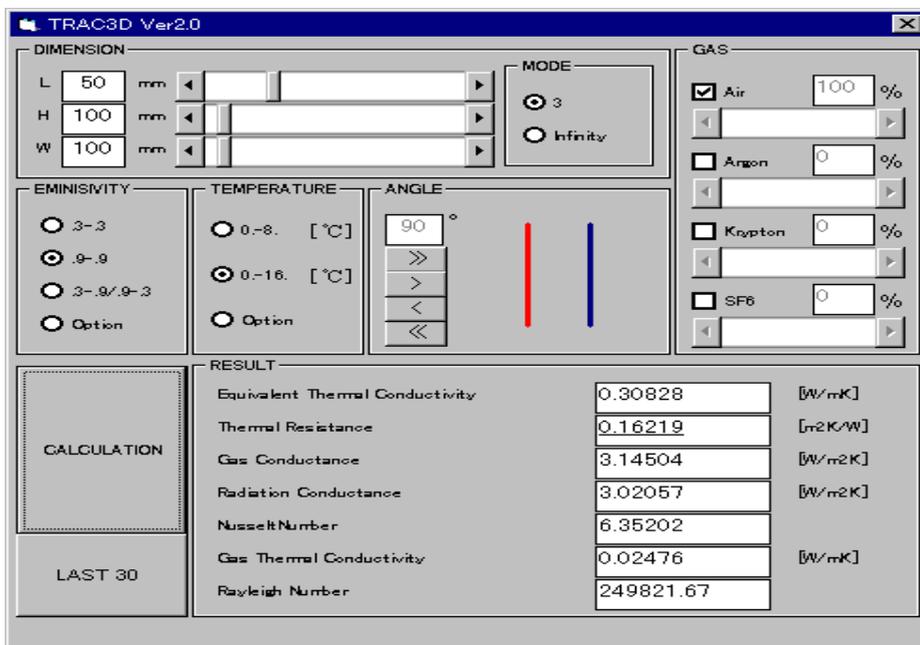


Fig.8. Display screen under executing TRAC3D (to compute thermal resistance of air cavity) attached to TB3D/FDM.

large. Therefore, it is necessary to numerically evaluate the reduction of the effect of thermal insulation and the risk of condensation. The procedure of 3-dimensional modeling for this part is explained as follows.

At first, three CAD figures viewed from each direction parallel to the 3-axis (X,Y,Z-axis) are drawn. Boundary lines between different materials are drawn using 2-dimensional CAD. The imaginary materials are added at interior and exterior surfaces according to the boundary conditions. In this drawing procedure, all boundary lines between different materials which appear on the same direction are superimposed in the same CAD figure. Therefore, the

cross section drawn like this is named a "transparent cross section". It must be noted that this is not a particular cross-section, but includes all of the boundary lines which appears all of the cross sections from the direction. Then, each figure is stored as DXF file. Three of the CAD figures (transparent cross sections) of the joint of balcony and wall are shown in Fig.4.

Next, the stored DXF file is read from 3-dimensional modeling tool attached to TB3D/FDM. This tool can select particular cross section from the transparent cross section and visualize it on the display. Looking at the display, users can select thermal property from the material table and assign it to each part of the cross section. Fig.5 is the display screen

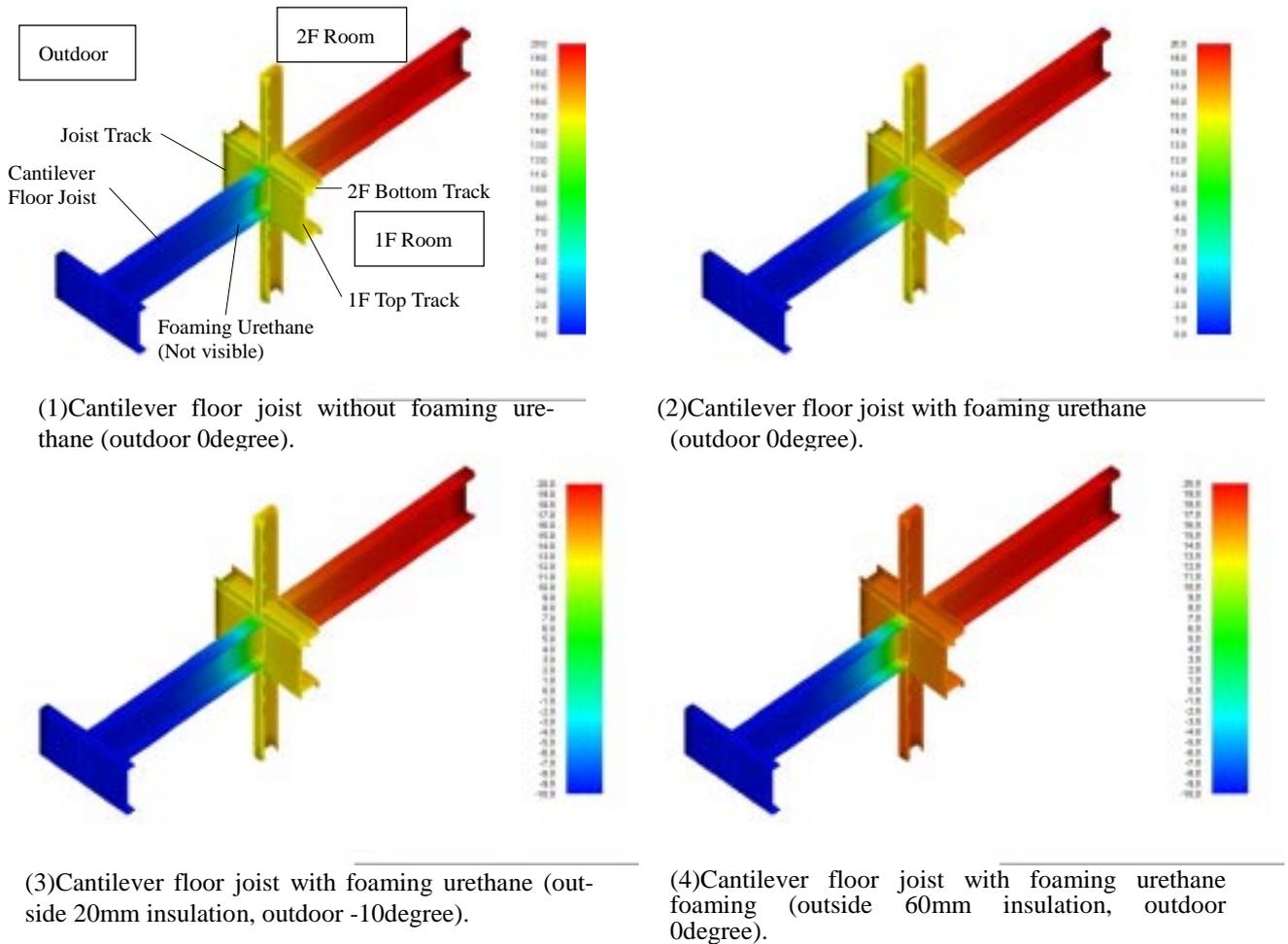


Fig.9. Temperature distribution example of a joint part of a balcony and an external wall.

illustrating the joint model. When material assigning procedure is finished, it is recommended to check the model from each direction (See Fig.6).

Finally, input data file for 3-dimensional calculation by TB3D/FDM and VRML file are automatically composed by the tool. Using VRML browser, the detail of the model can be 3-dimensionally reconfirmed (See Fig.7).

(2) Thermal resistance of air cavities

Air cavities with various shapes are contained in external walls, sashes and entrance doors. Thermal behaviors of these cavities give considerable effects on thermal insulation performance.

TB3D/FDM employs TRAC3D[®] to compute thermal resistance of these air cavities. This tool replaces an air cavity by a solid material having equivalent thermal resistance to that of the air cavity. This replacement enables TB3D/FDM to compute temperature distribution of the walls and sashes as a simple thermal conduction problem.

The display screen executing TRAC3D is shown in Fig.8. According to the integrated formulas on the Nusselt numbers of sealed air cavity, TRAC3D calculates convective heat transfer coefficient under

various condition, i.e., the shape and tilt angle of the air cavity, temperature difference of the surfaces, internal gas in the air cavity. TRAC3D also evaluates radiation exchange in 3-dimensional space to calculate radiative heat transfer coefficient. Then, TRAC3D calculates the equivalent thermal conductivity of sealed air cavity combining the convective and radiative heat transfer coefficients.

CALCULATION RESULTS

(1) A joint part of a balcony and an exterior wall

Temperature distribution calculation for a joint part shown in Fig.2 was carried out using TB3D/FDM. Steady state temperatures at all of the grid points were obtained. Temperature distribution of the steel surface is shown in Fig.9. Room temperature is set at 20 degree., while outside air temperature is 0 degree or -10 degree. An image processing software on the market was used for these visualizations.

Fig.9(1) and (2) show the effect of thermal insulation of the floor joist. The thickness of thermal insulation (represented by t_0 in Fig.2) is 20mm in these two cases. Fig.9(2) shows temperature distribution

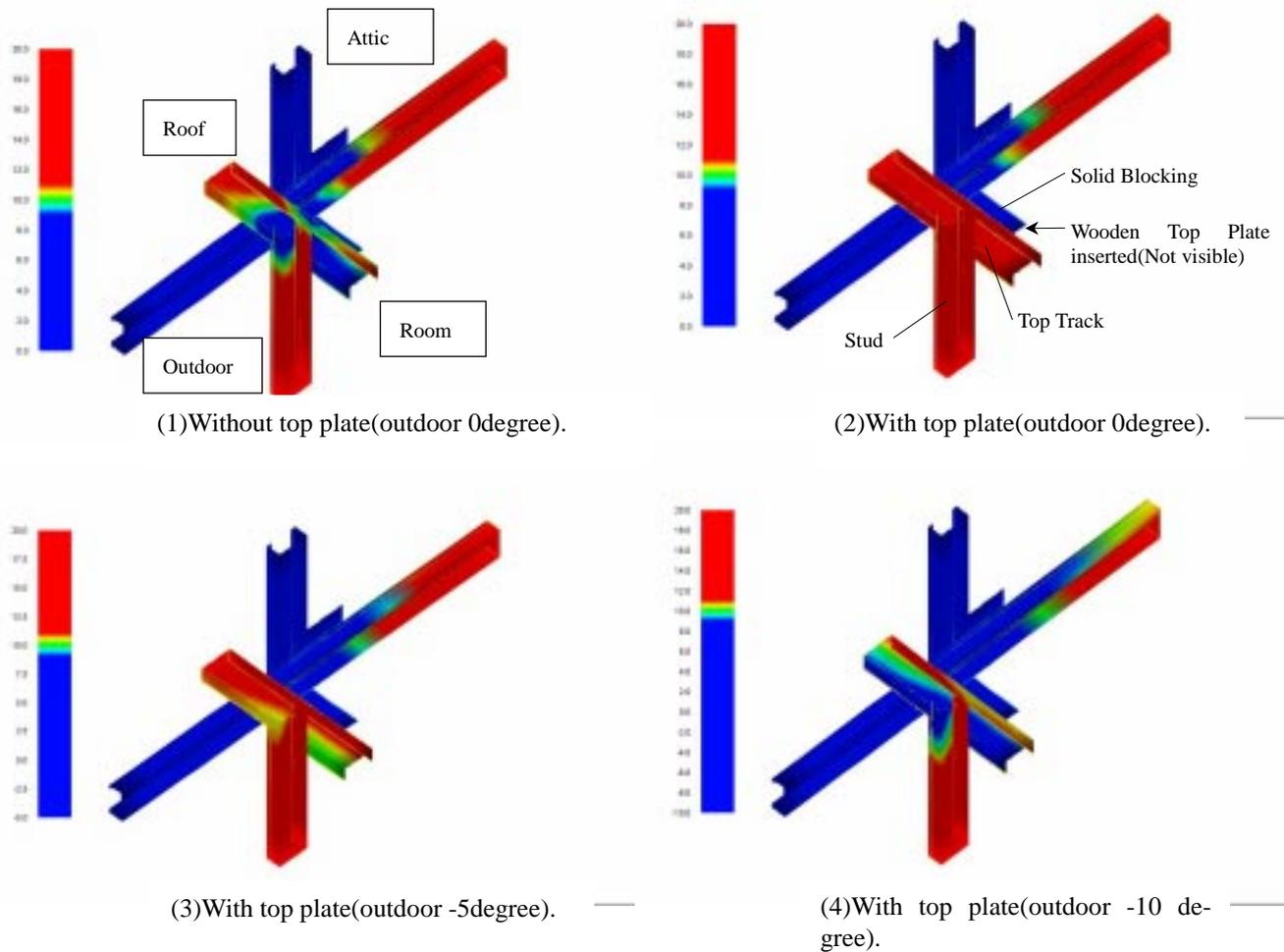


Fig.10. Temperature distribution example of a joint of a roof and an external wall with or without wooden top plate (Thickness of a external wall insulation are all 30mm).

corresponding to the part in Fig.2, while Fig.9(1) corresponding to the case when foaming urethane is attached on the outside surface of the cantilever floor joist in Fig.2(2). We can see temperatures on the inside steel surface of Fig9(1) are higher than those of Fig.9(2). This shows foaming urethane prevents heat loss from the outside surface of the floor joist. The effect of thickness of thermal insulation (represented by t_0 in Fig.2) was examined in Fig.9(3) and (4). The thickness is 20mm for Fig.9(3), while 60mm for Fig.9(4). We can see steel surface temperatures of Fig.9(4) are higher than those of Fig.9(3).

(2) A Joint part of a roof and an exterior wall

Fig.10 shows the temperature distribution of a roof-external wall joint part. Details of this part are shown in Fig.3. In Fig.10, temperature scales are set from 9 to 11degree in order to read minute temperature change around 10degree.

Fig.10(1) shows temperature distribution when there is no wooden top plate, while in Fig.10(2), as shown in Fig.3(1), wooden top plate is inserted between solid blocking and top track for thermal breaking. We can see surface temperatures of wall stud and top track are higher in Fig.10(2) than in

Fig.10(1).

Fig.10(3) and Fig.10(4) shows temperature distribution when outside air temperatures are set at -5degree and -10degree, respectively. In these two cases, wooden top plate are inserted as in Fig.10(2). These two figures show surface temperatures of the wall stud and top track becomes lower than those in Fig.10(2). Surface temperatures of wall stud and top track in Fig.10(4) is similar to those in Fig.10(1).

Therefore, it would be predicted that the countermeasure of adding wooden top plate is insufficient for colder regions to prevent risk of winter condensation .

CONCLUSIONS

- (1) Three-dimensional finite difference computer program named TB3D/FDM was developed.
- (2)TB3D/FDM calculates 3-dimensional temperature distribution for doors, windows and complicated thermal bridges of exterior skins of buildings.
- (3) Pre-processing tool is attached to TB3D/FDM that can assist users to make 3-dimensional input data.

(4) In TB3D/FDM, air cavities are replaced by solid materials with the same thermal resistance as those of the air cavities. The tool for this replacement named TRAC3D was also developed.

(5) TB3D/FDM can assess various thermal insulation specifications.

(6) TB3D/FDM can predict risk of condensation.

ACKNOWLEDGEMENT

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