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Impact of Insulation on Reduction of Energy Consumption in Buildings Based on Climate in Iran

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Abstract: In recent years, insulation is an important issue for reduction of energy consumption, in particular residential sectors. Present study deals with thermal performance and optimum insulation thickness of building including external walls, ceiling, floor and widows with various insulations under climatic conditions of Tehran, Iran. Rock wool, polystyrene and autoclaved aerated concrete (AAC) blocks as insulation material were selected. In addition, BCS19 simulation software, which designed by administrators of Iranian building codes, was used for determination of declining in energy consumption. Results showed that reduction in energy consumption for rock wool, polystyrene and AAC blocks insulations were 47, 46 and 35%, respectively. Also, optimum thicknesses of rock wool and polystyrene insulations were determined 60 and 30 mm for walls, 80 and 40 mm for roof and 40 and 30 mm for floor, respectively.

Key words: Energy Losses · Thermal Insulation · BSC Software · Heat Load · Energy Conservation

INTRODUCTION

In recent decades, due to population growth and world high energy demands certainly created an environment to conserve energy; therefore, use of insulation became an essential component in energy consumption management. Prevention of heat losses in construction and building has significant impact on reduction of fuel consumption. About 50 % of total energy in the world is consumed in construction and building; while most of the consumed energy was spent for buildings space heating [1-4]. Therefore, appropriate models for the analysis of energy consumption in buildings should be provided [5-10]. According to Iran energy agency 2012 edition, 40 to 60% of fossil fuel was used on housing costs in years 2005 to 2011. However, high dependence on natural gas in the domestic energy consumption had caused many problems in the cold seasons, especially in cold regions of many countries [8, 11-14]. In 2010 and 2011, an investigation has been carried out by Daouas *et al*. [15, 16] to find out the optimum insulation thickness in buildings based on Tunisia weather. They have reported that the optimum thickness of polystyrene insulation was 5.7 cm. In China, at the same year, the optimum thickness of extruded polystyrene insulation 5.3 cm was reported by Yu *et al*. [17]. In 2011 Ozel *et al*. [18, 19] in Turkey defined the optimum thickness of polystyrene insulation was in the range of 2 and 8.2 cm

In this paper, based on characteristics of Tehran climate and considering Iranian building codes, the optimum thickness of thermal insulation were determined. In random basis, an apartment was chosen; energy consumption for external walls, windows, ceiling and floor of the selected building were examined with several types of insulation. The obtained results were compared to each others. All the obtained data compiled sand the studies were carried out by BCS19 simulation software which designed by administrators of Iranian building codes.

Principles of Heat Transfer and Heat Losses in Buildings: The building is heated by different mechanisms such as conduction, convection and radiation. Radiation could be negligible for calculating the heat load in building during winter. Heat of building could be lost from the contraction joint of walls, roofs, floors, windows and air introduced into the building.

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Calculation of Building Heat Load: The building heat load is calculated based on the amount of heat losses from the warm room to the outdoors due to temperature gradients. These calculations are done according to the heat transfer principles. Rate of heat transfer from walls depend on their heat transfer area, temperature differences from inside and outside and heat transfer coefficients of materials which are used as composite walls. The maximum amount of thermal energy (heat load) must be added to make a desire condition by the heating system in building during cold season. This heat load should be accounted for choosing appropriate heating system. Due to reliability and simplicity of heat load calculation, solar radiation, heat generated by equipments and the ability to store heat inside building walls could be ignored.

Conductive Heat Transfer Through the Building Walls: The concept of overall heat transfer coefficient used to evaluate the heat losses from the building walls stated as follows:

$$Q = UA(T_i - T_0) \tag{1}$$

where, U is overall heat transfer coefficient of walls, A is surface area, T_o and T_i are outside and inside temperatures of walls, respectively. U represents the combined effects of heat transfer from different composite layers of wall, ambient air in the gap (if it exists) and the film of air nearby the inside and outside wall surface. Walls building are often composed of different layers of varying materials with different thicknesses. Conductive thermal resistance of the composite wall is the sum of conductive thermal resistances of different layers.

$$R_{e,cond} = R_1 + R_2 + ... = \frac{X_1}{K_1 A} + \frac{X_2}{K_2 A} + ... \tag{2}$$

where $R_{e,\ cond}$ is conductivity of thermal resistance of composite walls, X_1, R_1 are thickness and thermal conductivity of i th layer, respectively. The A is the layer heat transfer area. Thermal resistance of the air layer adjacent to the wall (inside and outside) is expressed by the inside and outside film coefficients. If there is a gap in the wall, thermal resistance of the ambient air must be considered. Thus, the thermal resistance of the air layer could be expressed as follows:

$$R_{e,air} = R_{si} + R_a + R_{so} = \frac{1}{f_i A} + \frac{1}{f_o A} \tag{3}$$

where $R_{e,\ air}$ is overall thermal resistance of the air, f_i is coefficient of the inside air film, f_a is coefficient of the ambient air film and f_o is coefficient of outside air film. Air film coefficient is usually considered to be constant. Also, outside air film coefficients depend on outside weather conditions especially local wind speed. It can be noted that the heat losses depend on wind speed and its direction. At first, heat is transferred to the exterior of building; while total thermal resistance decreases. Secondly, the cold air can introduce into the building from interstices of doors, windows and duct air conditioner.

However, the film coefficients of inside and outside of a building are almost constant values in a particular area. The total thermal resistance can be expressed as the sum of thermal resistances:

$$R_t = R_{e,air} = + R_{e,cond} \tag{4}$$

Also U is defined by the following equation:

$$UA = 1/R_t \tag{5}$$

It can be concluded that overall heat transfer coefficient can be controlled by modification of the thickness of the insulation, thermal conductivity of the layer and thickness of the air gap. If there is no limitation on insulation costs and occupied space by walls, thermal resistance of the wall could be increased. Thus, the wall heat transfer coefficient comes near to zero and then heat losses from the wall can be disregarded, but this is practically not possible.

Optimization of Insulation Thickness: Energy consumption is reduced by increasing the thickness of insulation. The optimal insulation thickness for improvement on energy efficiency was considered for different insulations. On the basis of following equation, optimal insulation thicknesses for different insulations were compared to each other and obtained results are reported.

$$\left(\frac{\textit{The amount of energy without insulation}}{\textit{energy consumption with insulated}} - 1\right) \times 100 = \textit{percent of ensrgy recovery} \tag{6}$$

Modeling for Building

Introduction of Software Which Used in this Study

BCS19: BCS19 is friendly use software. It is designed based on 19th Iranian building codes for conservation of

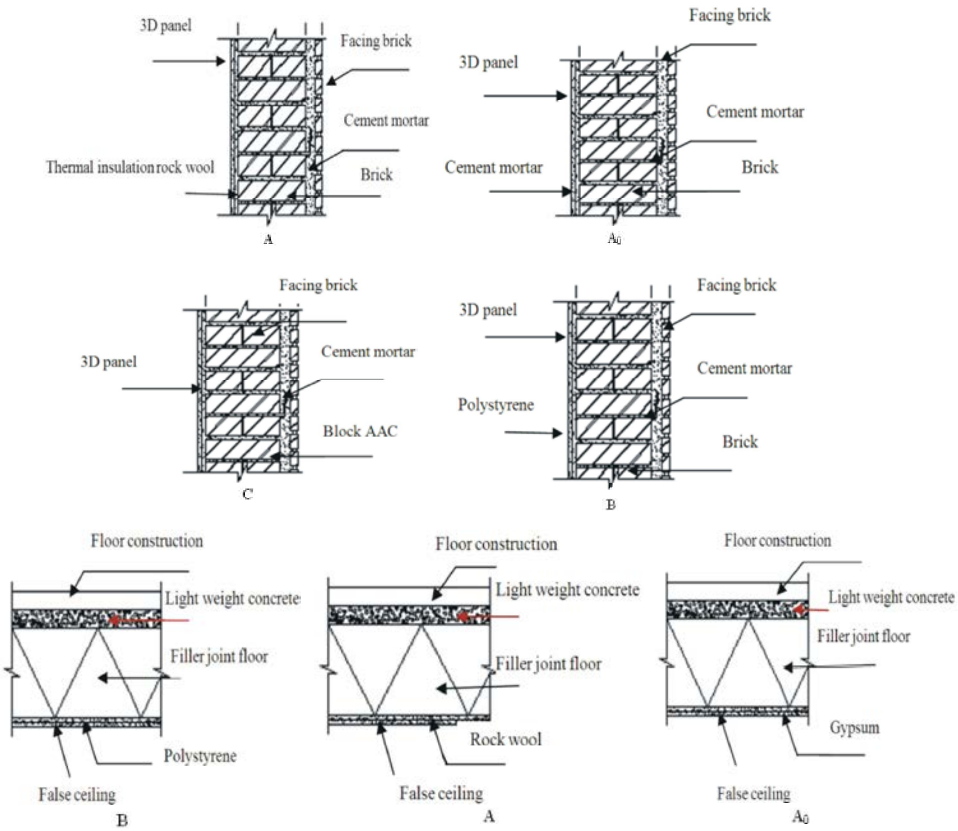

Fig. 1: The walls and ceiling operational details

Table 1: Thermal insulations properties used in modeling and their sites

No.	Details	Thermal conductivity λ (W/m. K)	Density (kg/m^3)	Thickness (mm)	Locations
1	Rock wool	0.041-0.047	80-150	25, 40, 50, 60, 80, 100	Wall, floor, deck
2	Extruded polystyrene (CFC)	0.033-0.37	25-40	15, 20, 25, 30, 40, 50	Wall, floor, deck
3	Block AAC	0.16-0.33	400-800	100, 120, 150, 175, 200, 250	wall
4	Window frame UPVC with double glazed	2.1-2.5	----	6, 8, 10, 12	window

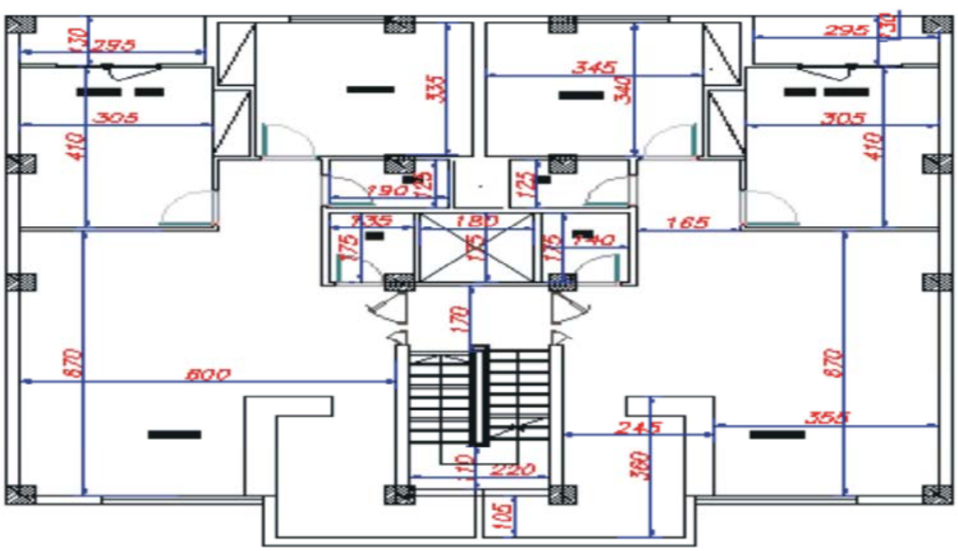

Fig. 2: Storey plan

energy consumption in buildings. Administrators of 19th Iranian building codes designed this software. User can select the building elements such as walls, ceilings, etc from defined elements by software. Then, software evaluates the designed buildings by the user with 19th Iranian building codes after that their fitness in energy consumption is reported.

Presentation of Case Study: Optimization of energy consumption in a building was investigated in capital city of Tehran. The specified apartment was positioned in a 4 storey building with, 8 residential units, which each residential unit has 80 m^2 areas. North and south elevation of apartment are 14.4 m^2; east and west elevations of apartment are 12 m^2. The north and south of out walls made contact with clearance. Also, the east and west side of the building were separated by contraction joint from nearby building that it is unconditioned space. The ceiling of the third storey and the floor of first storey are in contact with the clearance and unconditioned space. While, the roof of first, second and third storey are in contact with conditioned space. Therefore, there are no insulations required.

The external walls, windows, ceiling of the third storey and the floor of first storey were studied for optimization of energy consumption. Different insulations were examined for each section. Then obtained results were compared to each other and optimum thicknesses of insulations were determined. Three different kinds of insulations were considered for walls, including mineral thermal insulation (A), polymer thermal insulation (B) and blocks thermal insulation (C). In addition, both (A) and (B) insulations were separately applied for ceiling of the third storey and the floor of first storey which is made by filler joint with yonolit blocks. Also, UPVC windows with double glazed which is filled with argon (Ar) gas were compared to windows with aluminum frame with glass sheet.

Introduction of Building Insulations and Windows: Thermal insulations properties used in modeling and their sites were noted in Table 1. The walls and ceiling operational details are shown in Figure 1. It should be noted that details of the roof and floor insulation are equal; but floor construction was different; that has been considered in terms of modeling software.

RESULTS AND DISCUSSION

Energy Consumption for Walls: For duration of one year, thermal loading of building walls per meter square for

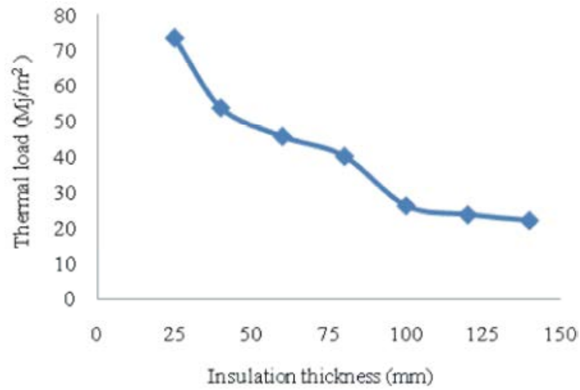

Fig. 3: Thermal loading of wall which insulated by rock wool insulation

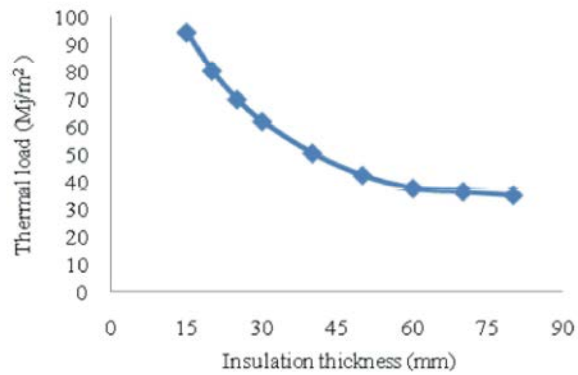

Fig. 4: Thermal loading of wall which insulated by polystyrene insulation

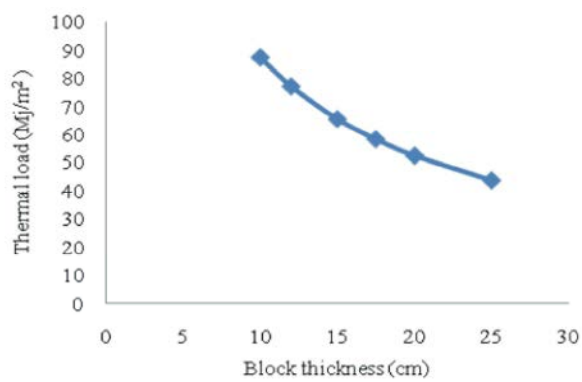

Fig. 5: Thermal loading of wall which insulated by AAC blocks insulation

insulation of rock wool, polystyrene and AAC blocks were illustrated in Figures 3, 4 and 5, respectively. Also, the obtained results were compared building without any wall insulations as shown in Figure 6. Based on presented data this figure, reduction in energy consumption for rock wool, polystyrene and AAC blocks in desired thicknesses were in the range of 54 to 83.5%, 40 to 73% and 45 to 72.5%, respectively.

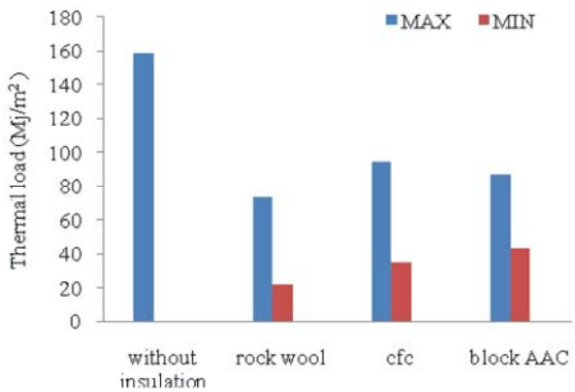

Fig. 6: Comparison of thermal loading between vary insulated wall and without insulation wall

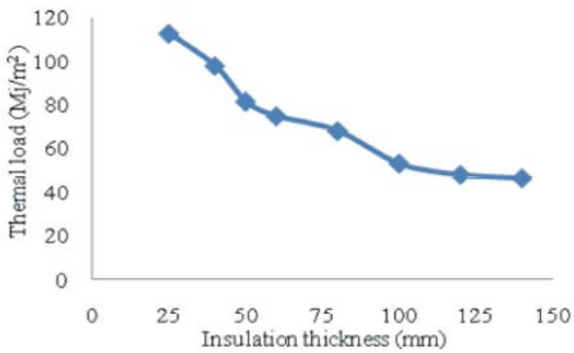

Fig. 7: Thermal loading of roof which insulate by rock wool insulation

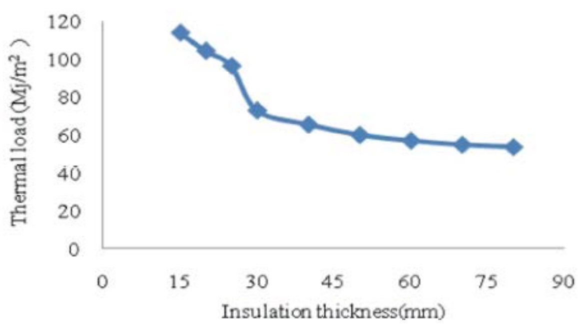

Fig. 8: Thermal loading of roof which insulate by polystyrene insulation

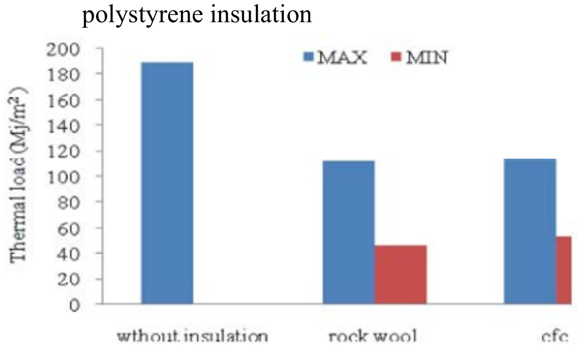

Fig. 9: Comparison of thermal loading between vary insulated roof and without insulation roof

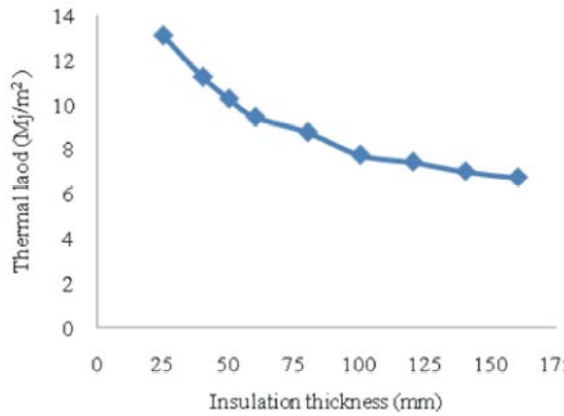

Fig. 10: Thermal loading of floor which insulate by rock wool insulation during one year

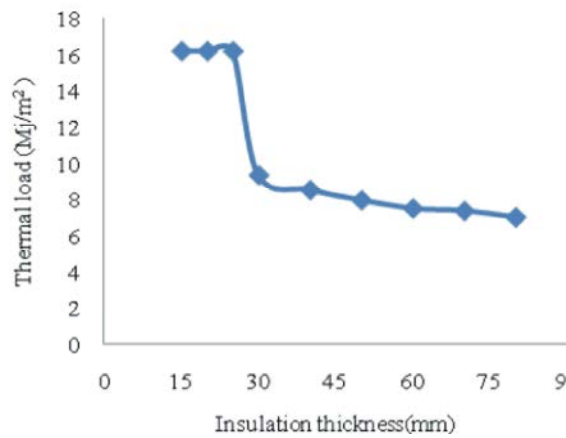

Fig. 11: Thermal loading of floor which insulate by polystyrene insulation during one year

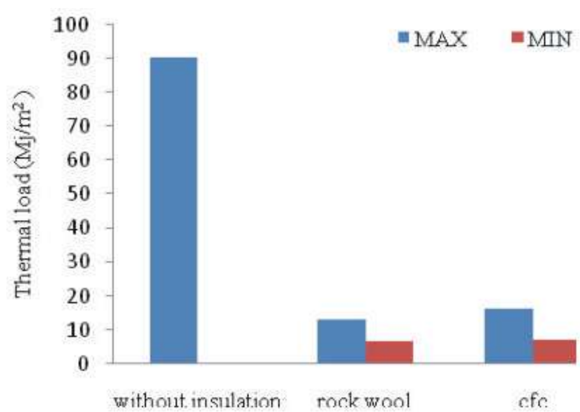

Fig. 12: Comparison of thermal loading between vary insulated floor and without insulation floor

Roof Details: The trend of energy consumption for the roof is illustrated in Figures 7 and 8 for duration of one year. In addition, two different insulations, rock wool and polystyrene were used for the roof, while the insulation

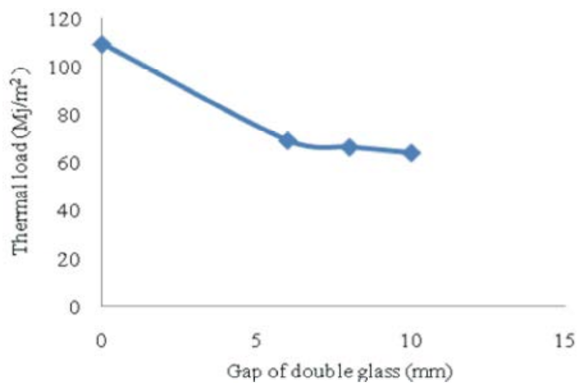

Fig. 13: Thermal loading of UPVC windows with double glass compared to windows with aluminum frame and glass sheet

Table 2: Optimum thickness of insulations

Insulations	Walls (mm)	Roof (mm)	Floor (mm)
Rock Wool	60	80	40
Polystyrene	30	40	30

thicknesses varied. According to the stated figures, reduction in energy consumption for rock wool and polystyrene insulations were in the range of 40 to 72% and 40 to 69%, respectively.

In addition, the sharp decreases were observed for rock wool and polystyrene insulation in thicknesses greater than 50 and 30 mm, respectively. It can be concluded that both insulations had approximately the same performances and the thickness of these insulations must be greater than the mentioned values.

Floor Details: Figures 10 and 11 are based on the amount of energy used for thermal insulation in the floor throughout the year. In this case, rock wool and polymer insulation were applied in different thicknesses and decline of energy consumption was between 88 to 93% and 85 to 93%, respectively. It can be seen from Figure 11 that 41% reduction of energy consumption was achieved for polystyrene insulation in thickness of greater than 30mm.

Windows Details: In Figure 13 energy consumption for UPVC windows with double glass compared to windows with aluminum frame and glass sheet was considered. Thus, a 41.5% reduction of the energy consumption was observed.

Optimum Thickness of Insulation: Optimum thickness of rock wool and polystyrene insulations were calculated for walls, roof and floor based on heat losses defined in Equation (1). The obtained results are summarized in Table 2.

CONCLUTION

The present work was carried out with the aid of BCS19 simulation software for consideration of the optimum thickness of insulations. External walls, ceiling, floor and widows of a random apartment with several insulations including rock wool, polystyrene and AAC blocks were investigated under climatic conditions of energy consumption in Tehran residential buildings. In this study, based on obtained results significant improvements were achieved using Rock wool insulation which was a good choice for some buildings. The base condition was set for the primary operation for buildings without walls insulation. Using of AAC blocks is suggested for some building which constructed based on optimum energy insulation rules.

If there is a limitation in building height, rock wool insulation was used for insulating the roof and floor with thicknesses of lower than 30 mm. However, for thickness of more than 30 mm, both rock wool and polystyrene insulation have the same yield in thermal performance.

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