CAD technologies under thermal properties analysis of wall cladding of framed buildings

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Abstract. Problems of energy-saving and efficient use of resources are currently becoming as important ones. Heat losses reduction in buildings deemed as end-use energy consumers is one of the most promising directions of energy saving. The aim of this analysis was the calculation of thermo technical characteristics of multi-storey residential building with reinforced concrete frame by simulating external walls using ANSYS software. 25-storey residential building with reinforced concrete frame in Ufa, the Republic of Bashkortostan was taken as the subject of research. Values of specific heat loss were obtained through the structural units and enclosure, on the whole, being reviewed, comparative results between calculations of main thermo technical characteristics of framed building was assessed by ANSYS software and by simplified table method as per SP 230.1325800.2015. Analysis of the air space inside the wall affecting specific heat loss through the junction with floor slab (perforation filled with heat insulation) has indicated that the air space inside the structure do not actually influence the heat loss for the low density blocks. Application of current software complexes like ANSYS is demonstrated as likely to be used for detailed scientific analysis of the possibility to increase enclosures thermal homogeneities. ANSYS may be used together with reference tables for specific heat loss for the junction between perforated floor slabs with the filler wall considering the air space inside it.

1. Introduction

Nowadays, Russia is taking active measures to save energy resources. Design engineering and installation of enclosing structures considering heat insulation thereof are of great importance in the construction industry taking into account energy saving [1]. In order to share of heat loss due to 1D heat-transfer is around 30-40% of total heat going through the structure because of non-homogeneities in available enclosing structures according to experts' opinion. This fact was recognized far in the latter half of the last century [2], but real opportunity to increase heat-transfer homogeneity of enclosing structures both in design and engineering solutions appeared together with development of regulatory changes [3, 4].

2. Bibliography

Procedure to define the reduced heat-transfer resistance was improved by new SNiP (construction rules and regulations) [3] thereby changing understanding of this value itself. Now the reduced heat-transfer resistance is to be understood as complex value characterizing the whole selected segment of building considering envelope the all current non-homogeneities. However, there is such a variety of

engineering solutions for enclosing structures together with non-homogeneities peculiar there to [5] that the simplified geometric layout of heat-transfer inclusions specified in previous heat insulation regulatory documents cannot be used in making due calculations and engineering design [6, 7]. Inconsistency of residential buildings, designed by SNiP 23-02-2003 before updating, with present standards by the reduced resistance values of external walls and by specific heat performance [8, 9] found by some scientists under analysis of cladding structural solutions is absolutely explained by this fact. It became possible with itemized approach to the reduced heat-transfer resistance calculation by temperature fields which procedure is indicated in new standards [3, 4]. Elevation of building is presented as a set of independent 2D, 1D and 0D (zero-dimensional) elements each thereof influencing upon heat loss through the enclosing structure section under review. Under the reduced heat-transfer resistance calculation of the enclosing structure section such approach enables to fix the "weakest" points or parts thereof in relation to heat protection and to improve them thereby reducing extra heat loss through structural components and enclosing structure on the whole. According to some authors' analyses the most efficient way to improve the building heat performance is to increase thermal homogeneity of external walls [10 - 12].

Various software packages [13 - 15] are currently applied for calculation of 2D and 3D temperature fields in the process of the reduced heat-transfer resistance values of external walls defining. In 2015 SP 230.1325800.2015 "Enclosing structures of buildings. Thermal homogeneity characteristics" regulation [4] containing reference tables of heat specific loss through some standard heat-transfer inclusions for the most commonly used engineering solutions to external walls came into force. Good repeatability was demonstrated by the study in calculating results of the reduced heat-transfer wall resistance by temperature fields using both software application and SP 230.1325800.2015 methods with reference tables [16].

3. Materials and methods

The research made by authors of this paper was focused on calculation of thermo technical characteristics of high-rise residential building with reinforced concrete frame by simulating external walls using ANSYS software. Construction volume of high-rise residential buildings (17-25 storeyed) with reinforced concrete frames in combination with thermal efficient walls [5, 17, 18] has been increasing recently in the Republic of Bashkortostan and its capital.

Main feature of filler walls is that they are not required to be load bearing because it is the frame of building that bears basic loading. Now three alternatives of engineering solutions in making external filler walls for the framed buildings in the Republic may be emphasized: wall made of load bearing structural insulating materials (autoclaved gas-concrete blocks) either brick-lined or plastered; back plastered three-layer energy-efficient wall; three-layer wall with ventilated façade.

Filler walls made of autoclaved gas-concrete blocks is likely to be the most technologically simple version for external thermal efficient wall among all the proposed engineering solutions. 400mm thickness of autoclaved gas-concrete blocks lying with density of 400-500 kg/m^3 in climatic conditions of the Russian central part absolutely provides for rated level of resistance to heat-transfer all around the wall [19, 20].

The following heat-transfer elements may be emphasized in external wall of this type: 2D – different kind of walls over the surface; linear – window jambs, roof junctions, inter-floor constructions, balcony slab, floor abutment to external wall along the ground; 0D – studs, reinforcing anchors, etc.

Let's take frame 25-storeyed residential building in Ufa, in the Republic of Bashkortostan with design indoor air temperature of 21°C as the subject of research. External walls are laid with gas-concrete blocks on adhesive mortar with density of 500 kg/m^3 and thickness of 400mm with 40mm hollows to be lined with 120 mm ceramic solid bricks [21, 22]. Volume of a building to be heated is $V_{от}$=52768.6 m^3 while gross area of external enclosing structures is $A_{н}^{sum}$=10992.65 m^2.
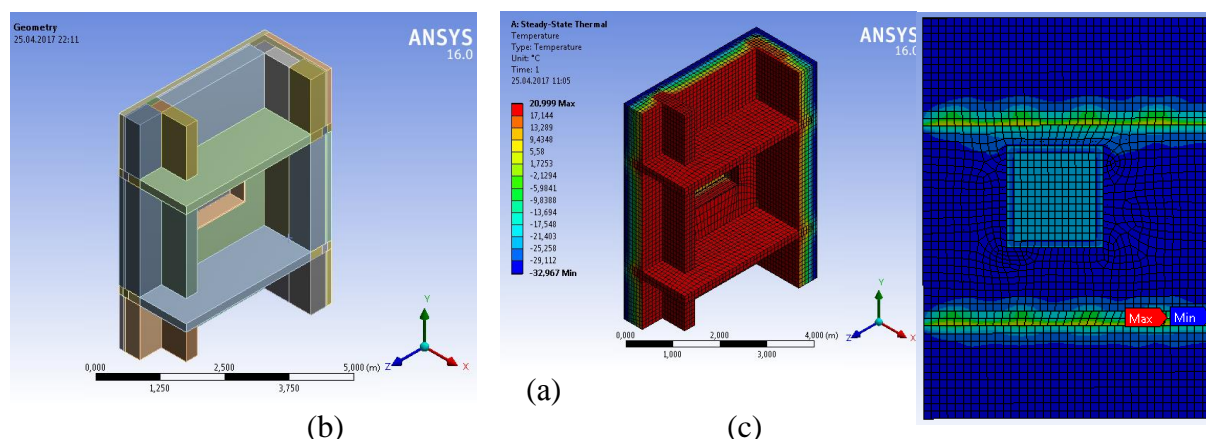
Figure 1. Computational model of external wall section: (a) – axonometric model; (b) – temperature field in 3D; (c) – heat flow distribution.

Section of filler wall made of gas-concrete blocks was simulated in ANSYS software to analyze level of the reduced heat-transfer resistance of enclosing structures and influencing by heat-transfer inclusions. Then we'll estimate the heat-transfer inclusions by the temperature fields. Model of enclosure section, temperature distribution and heat flows through the section are given in Figure 1.

The following elements in external wall of the building may be taken as the heat-transfer inclusions as per the figures: window jambs formed by lintel and masonry made of gas-concrete blocks on three sides, joints between (perforated) floor slab and wall [23, 24]. It should be mentioned from the figure that connection between filler wall and reinforced concrete pier is not thermal bridge as the pier is sufficiently insulated. Computational results of the reduced heat-transfer resistance of external walls using ANSYS software are presented in Table 1.

Therefore, the reduced heat-transfer resistance to thermal insulating layer of the building R_0^{np} amounted to:

$$R_0^{\max} = \frac{1}{0,4418} = 2,26 \frac{m^2 \cdot {}^\circ C}{W},$$

and thermal homogeneity factor amounted to $r = 0.67$, accordingly.

Computation of the reduced heat-transfer resistance to external wall, to specific thermal protective performance of the building and heat requirements used for heating and ventilation was also made using the reference tables of SP230.1325800.2015 either. Comparison of computational results according to two methods is given in Table 2.

As we can see from the table, the computational results of heating characteristics obtained with ANSYS software as compared with values obtained with SP are 6.1% higher by the reduced heat-transfer resistance to the wall, and 6.3% higher by thermal homogeneity ratio, and 4.3% and 3.2% lower by specific performance of heat requirements for heating and building ventilation and specific thermal protective performance, accordingly. Overall, the computational results strongly coincide.

It should be mentioned that air space between gas-concrete blocks and brick veneer was taken into account in calculation of the reduced heat-transfer resistance to external walls of the framed building when using ANSYS software (Figure 2).

Air space in the similar structural concept for junction between floor slab and wall is not regarded in SP 230.1325800.2015 reference tables for specific heat loss. Analysis of the wall air spaces effecting specific heat loss through the junction with floor slab (perforation filled with heat insulation) given in Figures 4 and 5 has indicated that cavities inside the structure do not actually influence on heat loss for the low density blocks, but reduce specific heat loss from 4.3 to 39.1% for masonries made of gas-concrete blocks or porous ceramics with coefficient of heat conductivity of 0.18 W/[m·°C] or higher (average density of 700 kg/m³ and higher).

Table 1. Computational results of specific performance of external wall elements using ANSYS software.

Structural element	Specific geometric parameter, m^2/m^2	Specific heat loss, $W/(m^2 \cdot °C)$	Specific heat flow stipulated by element, $W/(m^2 \cdot °C)$	Share of total teat flow through section, %
2D element 1 Over the wall surface	$a_1 = 0.301$	$U_1 = 0.296$	0.0891	20.17
2D element 1a Over the wall surface within balcony	$a_{1a} = 0.4283$	$U_{1a} = 0.236$	0.1011	22.88
2D element 2 Wall along pier	$a_2 = 0.0874$	$U_2 = 0.260$	0.0227	5.14
2D element 2a Wall along pier within balcony	$a_{2a} = 0.1833$	$U_{2a} = 0.208$	0.0381	8.62
1D element 1 Window unit-wall junction	$l_1 = 0.5615$	$\Psi_1 = 0.064$	0.0359	8.13
1D element 1a Window unit-lintel junction	$l_{1a} = 0.1519$	$\Psi_{1a} = 0.222$	0.0337	7.63
1D element 2 Wall-floor slab junction (balcony slab). 1/1 perforation	$l_2 = 0.285$	$\Psi_2 = 0.272$	0.0775	17.54
1D element 3 Wall-floor slab junction. 3/1 perforation	$l_3 = 0.158$	$\Psi_3 = 0.211$	0.0333	7.54
1D element 4 Garret floor junction	$l_4 = 0.018$	$\Psi_4 = 0.483$	0.0087	1.97
1D element 5 Slab over basement junction	$l_5 = 0.018$	$\Psi_5 = 0.094$	0.0017	0.38
Total	-	-	0.4418	100

Table 2. Computational results of specific characteristics of 25-storeyed residential building with reinforced concrete frame.

Item	ANSYS	SP 230.1325800.2015
1 Reduced heat-transfer resistance to wall, R_0^{max}, $m^2 \cdot °C/W$	2.26	2.13
2 Thermal homogeneity ratio, r	0.67	0.63
3 Specific thermal protective performance of building k, $W/(m^3 \cdot °C)$	0.149	0.154
4 Specific performance of heat requirements for heating and ventilation of building q, $W/(m^3 \cdot °C)$	0.23	0.24

As filler wall design made of gas-concrete blocks with air space more often occurs in climatic conditions of Bashkortostan, the authors have prepared a reference table "Specific heat loss for junction between the wall and perforated solid floor slab" (Table 3) to be used by design engineers. Air space thickness to be considered in computations is 40mm. It should be noted that air space thickness variation to 20-60mm slightly affects heat loss through this section.
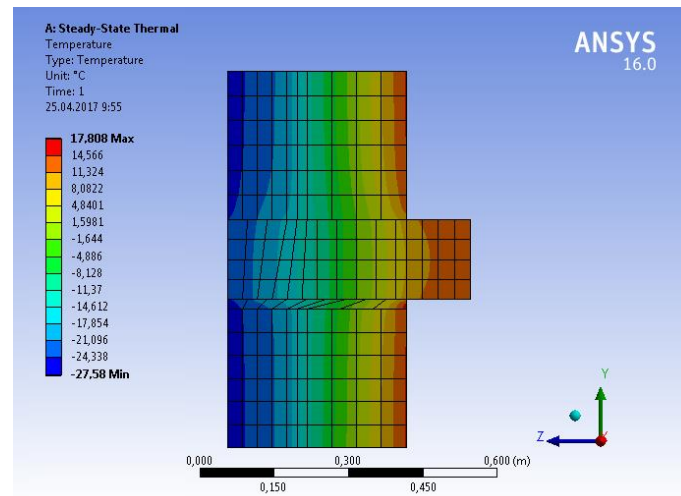
Figure 2. Temperature field of junction model between floor slab and wall made of load-bearing structural insulating materials veneered with bricks (with air space), 3/1 perforation.
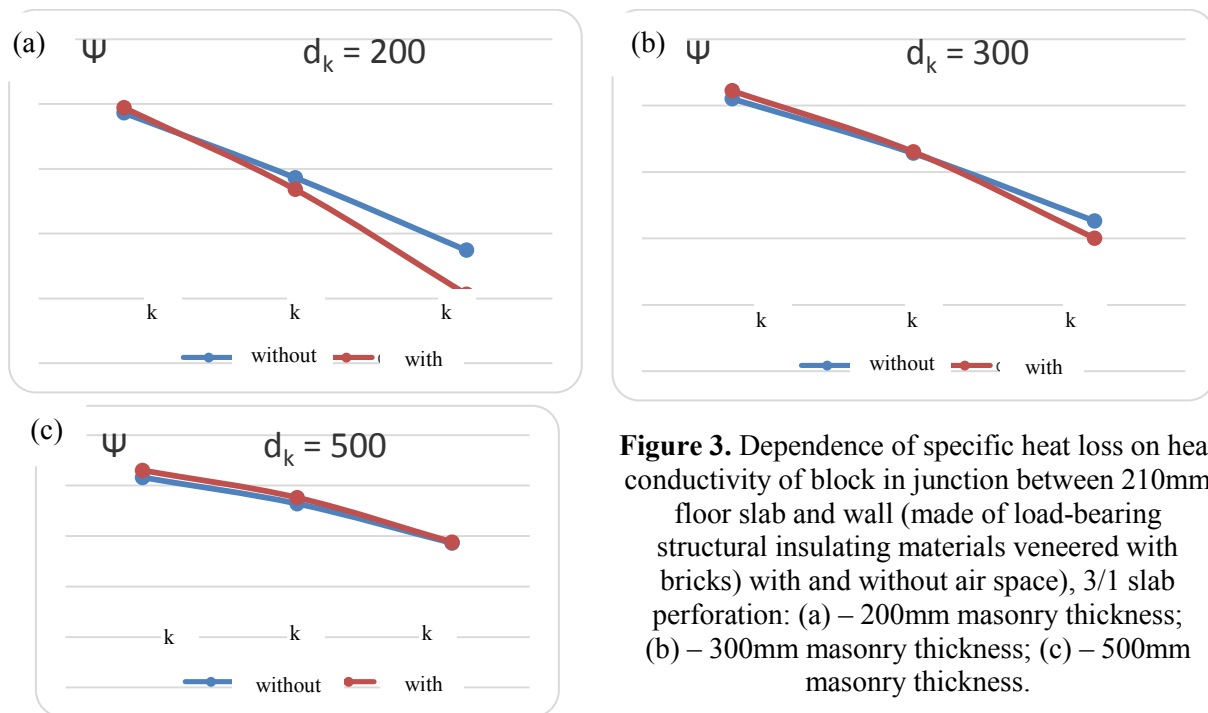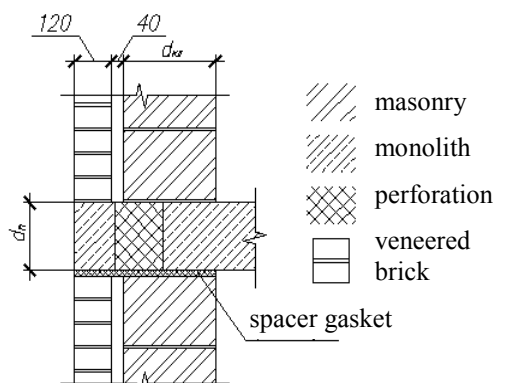

Figure 3. Dependence of specific heat loss on heat conductivity of block in junction between 210mm floor slab and wall (made of load-bearing structural insulating materials veneered with bricks) with and without air space), 3/1 slab perforation: (a) – 200mm masonry thickness; (b) – 300mm masonry thickness; (c) – 500mm masonry thickness.

4. Results

Therefore, in our opinion, under structural engineering of heat-shielding performance for residential and civil buildings reference tables from SP 230.1325800.2015 are advised to be used in the simplified engineering calculations, but such advanced software packages as ANSYS, in particular, are to be used in making detailed scientific analysis to increase thermal homogeneity of claddings. Besides, reference table for specific heat loss for junction between perforated floor slab and the filler wall taking into account air space was proposed to be used together with this software in addition to SP 230.1325800.2015.

Table 3. Specific heat loss Ψ, W/(m·°C) for junction between floor slab and wall. Masonry of lightweight concrete, extreme lightweight concrete, cellular concrete or large-size blocks veneered with bricks (with air space). 3/1 perforation.

| | $d_n = 160$ mm | | |
	$\lambda_k = 0,1$	$\lambda_k = 0,18$	$\lambda_k = 0,32$
$d_{kl} = 200$	0.156	0.116	0.074
$d_{kl} = 300$	0.166	0.135	0.096
$d_{kl} = 500$	0.169	0.15	0.12
	$d_p = 210$ mm		
$d_{kl} = 200$	0.193	0.143	0.087
$d_{kl} = 300$	0.205	0.164	0.113
$d_{kl} = 500$	0.208	0.182	0.143

masonry

monolith

perforation

veneered brick

spacer gasket

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