Search for Cold Bridges Based on the Building Information Model Collisions Analysis

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Abstract. The energy-efficient buildings construction requires careful consideration of the building external structures heat loss possible causes. One of the reasons for heat loss is the cold bridges presence in the building external circuit. This article discusses the material cold bridges causes, i.e. energy leakage through more conductive materials. Some analysis methods of cold bridges and possible methods of their elimination are considered. The main attention is paid to the automated search for cold bridges at the building design stage using BIM technologies. It is proposed to analyze the building information model data, using the geometric objects finding collisions method. The algorithm includes the building elements determination that crosses the building thermal contour and such elements materials analysis for their ability to heat transfer. The advantages and limitations of the proposed method are discussed.

Introduction
The vast territory of the Russian Federation has climatic conditions with low winter temperatures. The heat assessment inputs and losses are important. Heat energy losses in buildings can occur in the structures and parts made of materials with increased heat conductivity, where additional thermal insulation is not provided or impossible. The search for thermal or cold bridges is carried out in the constructed and operated building with a thermal imager on the coldest days of the year [1]. Then the defects made by the designers and builders can be seen. Unfortunately, not all the defects can be eliminated after construction, which leads to increased energy consumption during the heating season.

The cold bridges search and analysis is relevant for many types of building external constructions [2, 3]. It is known that cold bridges are formed in the structures of windows and external doors, in the monolithic frames’ nodes, in the walls on the basis of thin-walled metal frames, in the balconies’ structures, in the seams of masonry walls [4, 5, 6, 7].

Special methods are used to prevent the cold bridges occurrence at the design stage. For example, the choice of materials with low thermal conductivity [8], the use of an additional insulating layer on the wall metal elements [9], the thermal breaks design in structures [10]. Intersections of point elements with a heat-insulating layer of external structures of the building should also be controlled.

Special methods are used to reduce the materials thermal conductivity in the construction process [11]. For example, perlite sand is used to prepare the masonry grout. Another method is to perform the insulating materials sputtering in the metal structural elements areas.
Software for mathematical modeling and the effects evaluation of the materials increased heat transfer can be used [12]. There is software that allows to build temperature fields in a given wall section, taking into account the materials of the layers of the wall and their thermophysical characteristics, but the necessary places of the sections of the wall are determined and set by the user.

The use of building information modeling (BIM) technologies provides new opportunities for solving traditional tasks of designers [13, 14]. The building information model is designed to create, store, process and transmit information about the geometric, physical, technological and other characteristics of the construction object. The construction projects information modeling becomes a tool to improve the entire construction industry in Russia. The task is to use the building information model in order to manage the full building life cycle.

Materials and Method
The building information model basis is a three-dimensional object-oriented building model, which carries information about the building object’s geometric characteristics. In addition, the model is able to store all sorts of other types information and their relationships. Such a variety of structured information makes it possible to apply the data extraction automated methods and processing to solve a wide range of tasks of designers [15]. To assess the model geometric information quality, a collision check is used, i.e. the surfaces intersection of the model elements with each other.

The verification algorithm allows to find the element’s doubling, the elements’ suppression and contact, the impermissible proximity of elements to each other. Information modeling software allows to create not only the real building structures geometry, but also the virtual objects geometry, such as danger zones around construction machines, construction workspaces, etc. Such virtual objects can also participate in the collision check [16]. Modern means of algorithmic design allow to automatically create the necessary geometric shapes in building information models for the specified conditions.

The purpose of this work is to offer an algorithm for the cold bridges automated search based on the building information model data analysis. The searching method for building information model elements geometry collisions is chosen to search for possible cold bridges.

The initial information for the collision search is an information model of the building with known data on the geometry of structural elements, their structure, materials, and thermophysical properties of materials.

Creating and preparing models to find collisions can be carried out with the help of the software for building information modeling, for example, Revit. Collision search can take place both in the information modeling program itself and in special programs for creating summary information models, for example, Solibry. To build additional virtual structures, it is required to use the algorithmic design with special software application, such as Dynamo.

Results
The proposed algorithm consists of a sequence of steps for automated construction of additional virtual structures of the outer wall. To perform it, it is necessary to have an information model of the building with a known structure of the layers of the outer walls and with defined characteristics of the materials of the layers of the walls. Additional geometric constructions are carried out to create virtual shells from the outside and from the inside of the walls (figure 1).
1. On each external wall of the building, virtual surfaces of the walls are formed along the external face (figure 2a).
2. The thickness of the surface (t1) is set taking into account the distance from the outer face of the wall to the thermal insulation layer. Virtual exterior wall are formed (figure 2b).
3. Virtual external walls are connected in a continuous shell (with variable thickness).
4. The intersections of the outer shell elements of the building (excluding walls) are found. A report on the intersections is made.
5. On each external wall of the building, virtual surfaces of the walls are formed along the inner face (fig 2a).
6. The thickness of the surface (t2) is set taking into account the distance from the inner face of the wall to the thermal insulation layer. Virtual internal walls are formed (fig. 2c).
7. Virtual interior walls are connected in a continuous shell (with variable thickness).
8. The intersections of the inner shell elements of the building (excluding walls) are found. A report on the intersections is made.
9. The results of two intersection tests are compared. Common elements are identified. These elements are simultaneously located on both sides of the insulation layer.
10. Heat transfer coefficients of materials of the found elements are determined. Cold bridges are detected.
11. Temperature fields in the zone of found cold bridges are studied.
12. The project solution is formed.

Figure 1. Virtual wall shells

Figure 2. Structure of wall
Summary
The proposed algorithm makes it possible to find the structures intersections and point elements of the information model with the building external structures heat-insulating layer. It should be noted that the information model should combine information about the architecture, structures and engineering systems. If the engineering information is separated into different disciplinary information models, the inspection can be carried out separately according to the disciplinary information models types. For example, the virtual wall shells intersections with architectural designs can be analyzed in an architectural disciplinary model, intersections with structural elements can be analyzed in a joint architectural and structural information model. The intersection with utilities can take place in the disciplinary model of the respective engineering systems.

The information model elements detailing level should not be lower than LOD 400. Reinforcement, beams above the windows and other metallic embeds, fasteners and pipes are to be represented in the information model as separate elements.

Door and window openings are not taken into account while creating virtual wall shells. In case of checking the intersection of virtual wall shells with windows and doors, it is necessary to disable it. The joints of the walls with windows and doors are known places of heat loss, where designers should always think of a rational solution.

In the object-oriented structure of the information model, virtual wall shells can be classified as walls. This category can be stored and transferred in standard files, including an open standard IFC file.

The presented algorithm can have features if the wall structure does not have a thermal insulation explicit layer. In this case, the outer and inner virtual shell of the outer walls will have a thickness equal to half the wall thickness or you it is needed to set a specific shells thickness value.

The algorithm does not take into account the composite walls of the building, when the height of the wall has a different structure, thickness and material layers.

The algorithm does not take into account the step change in the position of the walls (Fig. 1c).

It is necessary to create an algorithm for the step docking formation of walls in a continuous wall shell.

It is necessary to develop and propose the building complete closed outer shell creation, taking into account the roof and foundation structures.

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