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Digital X-Ray Flat Panel Housing for Operation at Extremely Low Temperatures

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Abstract. The paper presents the housing wall structure for the digital X-ray flat panel which can operate in extremely low temperature conditions. A technology of three-dimensional printing is proposed for making the detector housing with heat conductors incorporated in its wall structure.

Introduction

A housing construction is one of the most important stages in the creation of the electronic equipment. A housing is a multifunctional block which not only incorporates components, boards or blocks of devices, but also protects the electronic components against external mechanical and negative environmental attacks, such as excess moisture, for example. In addition, a housing protects a user against electric trauma and other negative factors arising during operation of the electronic equipment. There is an array of specific features which should be considered during these products development. Therefore the housing design requires individual approach even for single-type electronic devices. Moreover, manufacturers should take due account constantly changing marketing conditions. Thus, user feedback makes manufacturers constantly improve their products.

One should bear in mind that electronic components are regularly updated, such that if the lifetime of device is rather long, it is necessary to find original components for its repair or improvement which becomes increasingly difficult at initial design stages.

Standardized housings are usually used in case of provision of a single peace production. Such housings cannot provide optimum operating conditions for a product; they only protect their contents against mechanical attacks and prevent a user from electric traumas. In some cases, however, housing does not provide this minimum set of requirements and is merely a bearing component.

The additive technology or three-dimensional printing is one of the most dynamically developing technologies. Three-dimensional printing of metallic materials is currently at the initial stage of its development whereas that of polymer materials is being rather developed and allows producing objects of any complexity at high speed. However, polymer materials may not be appropriate for operation in certain conditions, for example, ionizing radiation. These circumstances must be taken into account when constructing housings for X-ray detectors and other devices of digital and analog X-ray systems.

X-ray Flat Panel Detector

Operation of a conventional X-ray detector is similar to that of a luminescent screen or a radiographic film intended for both direct and indirect transformation of radiographic image to visual image. Relatively widespread are X-ray flat panel detectors which represent matrix detectors as illustrated in Fig. 1 [1]. These detectors operate similar to complementary metal-oxide-semiconductor (CMOS) circuits used in ordinary digital cameras.

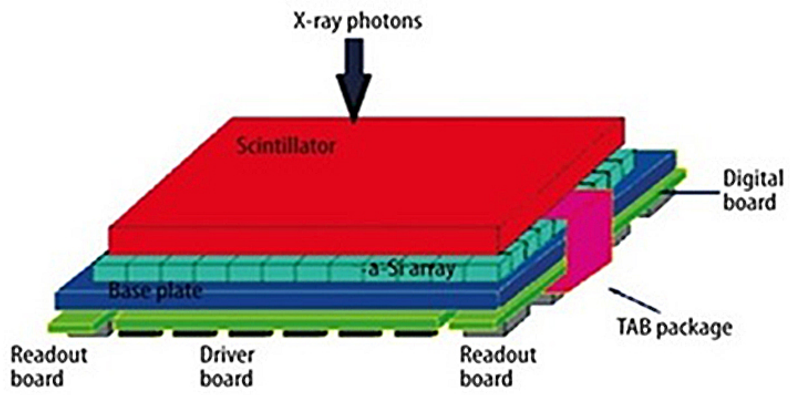


Fig. 1. Schematic of X-ray flat panel detector

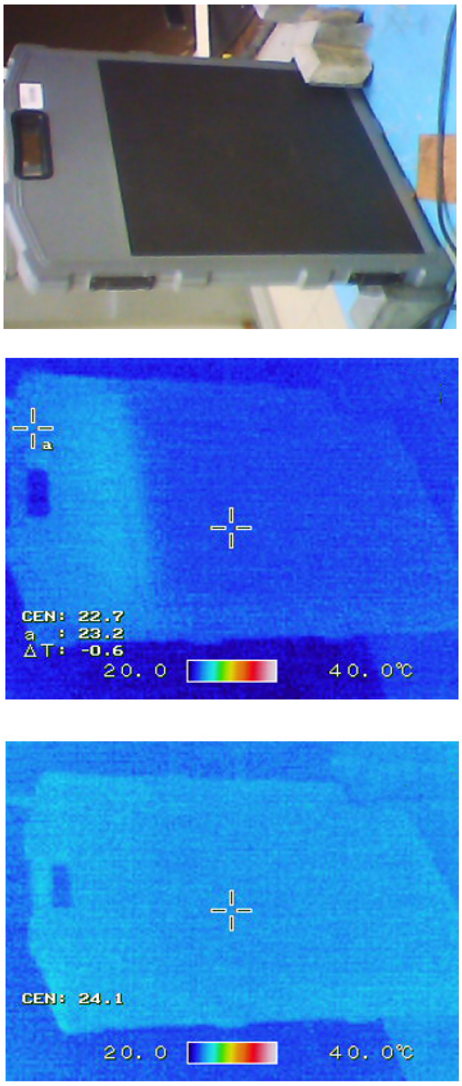
A wide use of X-ray flat panel detectors in extremely low temperature conditions is hampered by the fact that their assembly components are very sensitive to the ambient temperature. In north areas, the application of such detectors in non-destructive testing of welded joints of main pipelines is rather difficult due to complex natural and climatic conditions. For example, the pipeline ‘Sila Sibiri’, Russia, is laid on the territory of Yakutia. In winter, the temperature lowers down to –50°C and lower. Such temperature conditions exert a negative effect on hardware components of electronic devices causing, at least, distortion of the results obtained [2] and reduction of their operational life. In electronic devices, specific physical processes occur under low temperature conditions, such as mechanical damages due to either reduction in thermal strength of assembly components or deformation caused by the difference in thermal expansion coefficients of assembly components made of different materials. Consequently, there is a need to heat up the device and stabilize temperature conditions for its operation.

As it is known during operation of the electronic equipment a certain amount of heat releases into the environment due to Joule's losses in active elements of radio electronic circuits. At the efficient arrangement of assemblies and blocks in the housing, the excess heat can be used to stabilize the internal temperature of the device.

Methods

The Perkin Elmer XRD 0822 AP3 IND X-ray flat panel detector (Fig. 2a) was used in our experiment for assessing the contribution of the heat generation to heating the electronic device which can operate under low temperature conditions. After switching on, the temperature control was performed at different parts of the flat panel detector. NEC thermal imager was used to measure the temperature differential. Figure 2 presents the temperature field images of the flat panel detector in the idle state and after 20 minutes of its operation.

In Figure 1b, the right part of the flat panel detector is darker than the left. This indicates to its receiver portion which is a cesium iodide (CsI) scintillation crystal. According to this figure, the temperature of the matrix detector increases only by 1°C even after its long-term operation. Apparently, the heat generated during the operation is insufficient for the thermostat control of the device. Therefore, it is more expedient to employ an external heat source for heating up elements of the X-ray flat panel detector. In this case, all the portions of the matrix detector, central and remote, are supplied with heat. However, we should bear in mind not only the large matrix size of 200×200mm, but also the presence of other electronics in the flat panel detector, sensitive to the ambient temperature. All these electronic components are positioned in various places of the housing. That is why a heater unit should have a larger size which corresponds to the overall dimension of the matrix detector and electronic components locating outside its plane and requiring heating. However, such a heater should have heavy weight and thus requiring significant power consumption. In this case, heat transfers to those panel areas that do not need it, thus such a heater unit is ineffective.



a)

b)

c)

Fig. 2. Physical configuration of the X-ray flat panel detector (a) and images of temperature fields in idle state (b) and after 20 minutes of its operation (c)

A low-size heater unit with the required capacity can be used for the address heat delivery to the proper areas. It is, for example, either a standard heater generating heat owing to Joule's losses or the Peltier element. Although the latter is low-efficient and low-sensitive to frequent start/stop modes, its advantage is in the heat (or cold) generation provided by its different sides. Such a point heat generator can be arranged in any appropriate place without increasing or insufficiently increasing the size and weight of the final product. Heat (or cold) generated by such a heater is delivered to the appropriate assembly components *via* special-purpose heat conductors.

Heat conductors represent capillary-driven heat pipes, the latter are steam condensing devices which apply capillary forces to provide the heater motion and heat transfer, and perform a closed-loop operation [3,4]. The incorporation of heat pipes into the construction of the flat panel detector is complicated by the requirement for the optical transparency to be provided within the range from $\sim10^{3.1}$ to $\sim10^{-2}$ Å ($\sim10^{-7}$ $\sim10^{-12}$ m) or the uniform transparency, since the housing wall structure should not affect the quality of X-ray shadow images. Therefore, the structure of the heat pipe should be continuous and uniform.

Housings for digital X-ray flat panel detectors are usually made of plastic, often acrylonitrile butadiene styrene (ABS) or polycarbonate (PC). Housings are manufactured by the pressure casting technique which imposes certain restrictions on their construction. Thus, for example, housing should possess strengthening ribs to provide sufficient strength; fasteners, fittings and tails are needed to provide assemblability; the casting technology requires casting slopes, *etc*. All this reduces the usable space inside the housing and stands in the way of free convection flows. As it can be seen from Fig. 1, heating of the matrix detector can be provided only on the side of the base plate. As for scintillators, they are heated only by air inside the housing. During rather a long-term operation, in extremely low temperature conditions, such an amount of heating is clearly not enough.

This situation can probably be tackled by using special-purpose thermally conductive polymer materials, namely Teplostok and CoolPoly plastics [5-10] which are polymers with enhanced thermal conductivity. Thermal conductivity of plastics can be improved through the inclusion of high-thermal conductivity materials such as carbon, copper, aluminum oxide, and some others in the mixture. Nevertheless, the fabrication of housing for the X-ray flat panel detector capable of providing mechanical protection for electronics, safety for users and thermal stabilization inside is still rather difficult at the minimum level of production accessories.

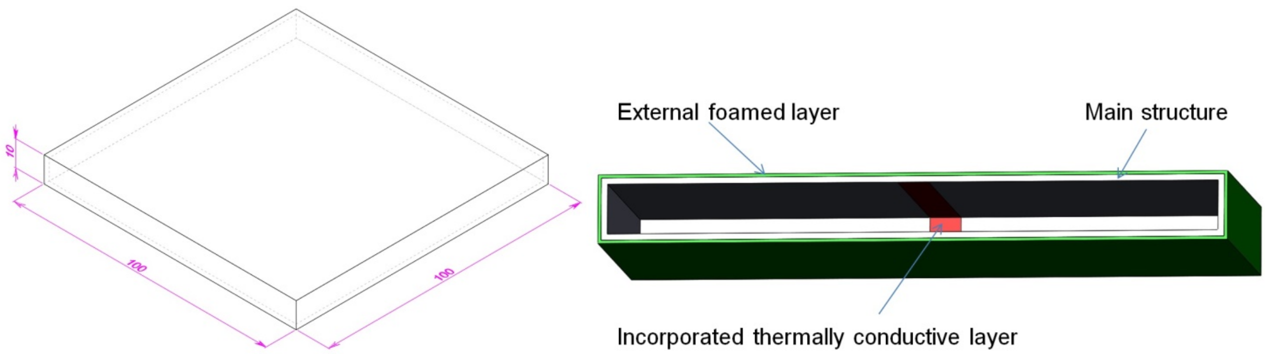
The additive technology application allows achieving particular results. The advantage of this technology includes creation of products of any degree of complexity. Moreover, any required structure of material can be formed during the printing process. For example, internal channels with specified size and topology which are impossible to obtain during casting processes [11, 12]. Drawing attention to the fact that in the case of a multi-filament extrusion line, the product can be obtained from several materials with different properties, the use of 3D printing in housing making seems to be very promising.

The most appropriate for the use in the housing fabrication are polyaryletherketone (PAEK) polymers, semi-crystalline thermoplastics with high-temperature stability and working temperature ranging from –40 to 260 °C. PAEK polymers are less sensitive to the radiation effect. For example, for polyaryletheretherketone (TecaPEEK) polymers, the ionizing radiation dose which reduces thermal elongation of material less than by 25 %, is 20000 kGy, and for TECASINT polymers it is 40000 kGy [6].

In order to assess the feasibility of creating a thermostable housing for electronic device, we develop a housing for practical use, made of material of inhomogeneous structure. The outer wall of this housing is made of three types of material, namely: a layer of continuous and uniform TECAPEEK plastic ensuring mechanical and electrical protection; a foamed layer of TECAPEEK plastic obtained by printing a porous layer in the form of hexagonal prisms, filled with air to ensure heat insulation; and a thermally conductive layer of Teplostok plastic. A 3D printer with a dual-extrusion print head is required to make such a housing.

The three-dimensional model of the multilayered wall structure is presented in Fig. 3a. In order to reduce the computation complexity, this model is closed and unsplit one. The solid modeling of this housing is implemented in DS SolidWorks 2016 CAD system.

For comparison, we design a housing model made of homogeneous TECAPEEK plastic. This housing model has the same mechanical strength and internal volume, but different wall thickness and, as a consequence, total weight (Fig. 3b). The safety factor is used for comparison. Table 1 summarizes the weight and size of obtained solid models of the housing with various wall structures.



a) b)

Fig. 3. Three-dimensional view of solid model of hosing: *a* – physical configuration; *b* – cross-sectional view. Red color indicates areas with thermally conductive properties

Table 1. Weight and size of solid housing with various wall structures

Housing wall structure	Weight [g]	Size (length-width-height) [mm]	Safety factor
Two-layer	27.9	101 × 101 × 11	1.4
Uniform	26.6	100 × 100 × 10	1.4

Experimental

Mechanical strength and thermal conductivity of the housing walls provided with heat conductors are evaluated *via* its computer simulation in ANSYS 18.2 finite element program.

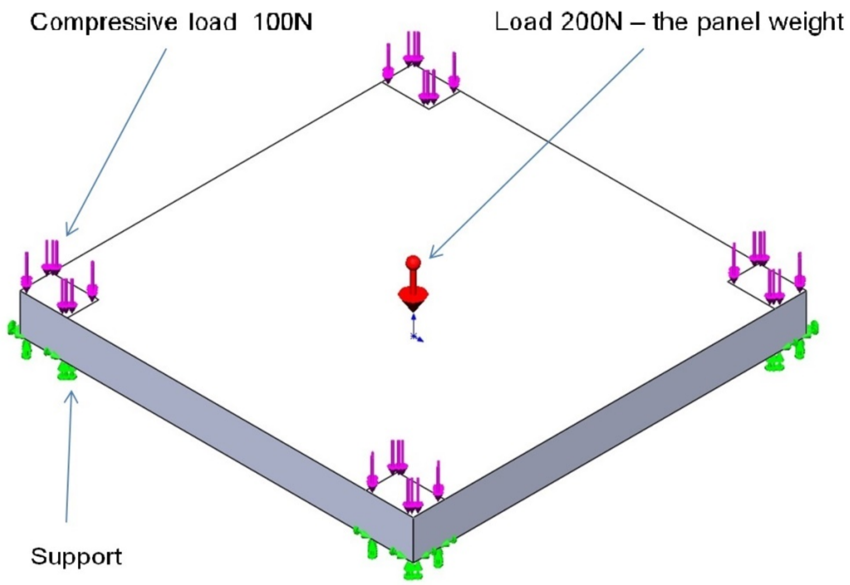
Mechanical strength test conditions include two static loads: 100N – the load on the side of jaws supporting the panel with communication and supply cable and 200N – the panel weight. The loading scheme of X-Ray scanner's structure is described in [13]. The test results obtained after the finite element modeling (FEM) are depicted in Fig. 4.

According to Fig. 4, the stresses in the housing walls do not exceed values allowable for most of polymer materials. Thus, the highest von Mises stress is 16.5 MPa. It should be noted that PAEK polymers are characterized by rather high values of mechanical strength which exceed the similar values for ABS, PA (polyamide) and PC plastics [14-16]. The obtained values of the safety factor amount to not less than 4.12, that fully meets the requirements for mechanical strength of the housing walls with a complex inner structure which acts as a heat conductor.

As shown in Fig. 4, the mechanical strength of the multilayered housing walls is not a limitation on its use in the structure of the X-ray flat panel detector. And the increase in its weight and size is insignificant (less than 1%) as compared to the housing walls with the continuous wall structure.

The estimation of thermal conductivity of the housing walls is carried out at –10°C ambient temperature, 10 W power of the internal heat source, and 15°C heating temperature [16]. The FEM results of this estimation are illustrated in Figures 5 and 6.

Figures 5 and 6 illustrate the distribution of temperature fields inside the ordinary housing walls and housing walls with the multilayered structure, respectively. It is clear that in the first case, the heat distribution is uniform, and all of the assembly components are subjected to heating, including those not requiring it. In the second case, distribution of the temperature fields occurs in areas nearby the heat conductors, thereby providing efficient heating of the assembly components to be heated.



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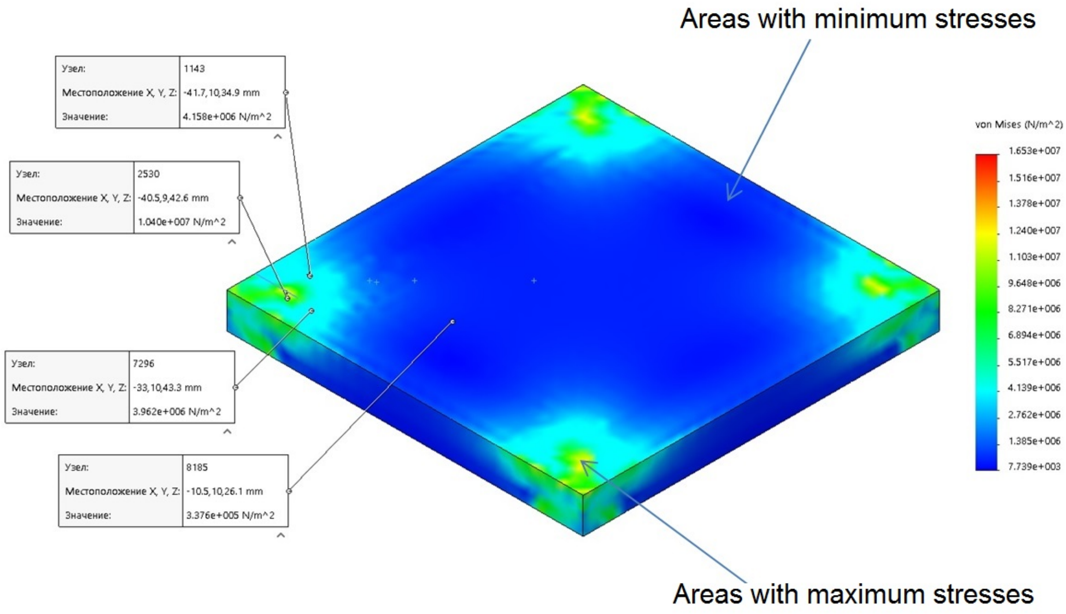
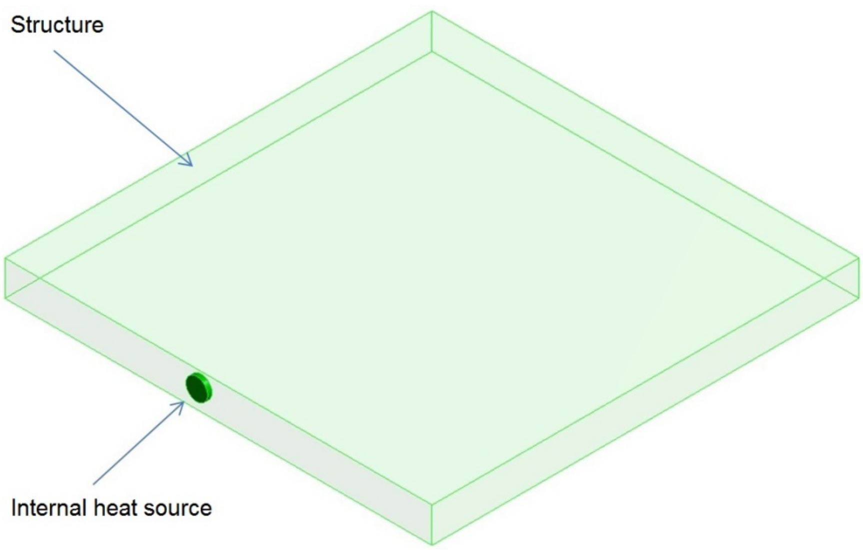


b)

Fig. 4. FEM of multilayered housing walls under mechanical loading:
a – scheme of static loads; b – von Mises stress



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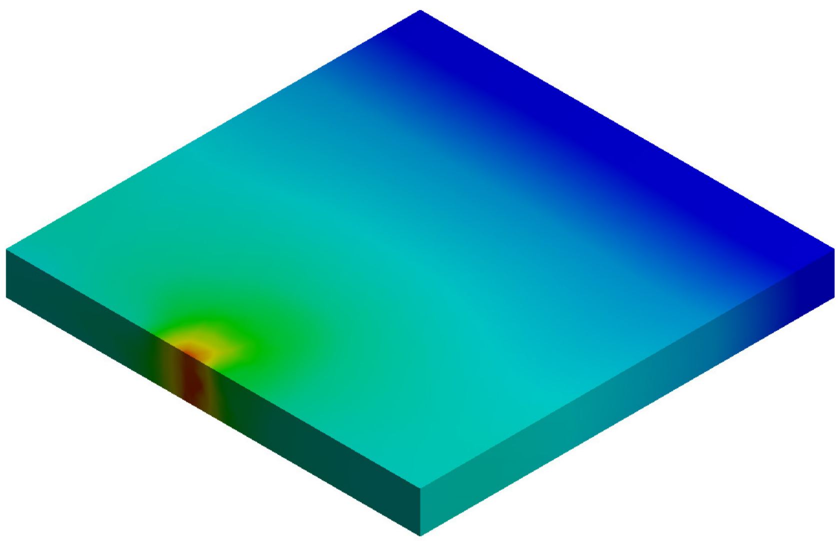

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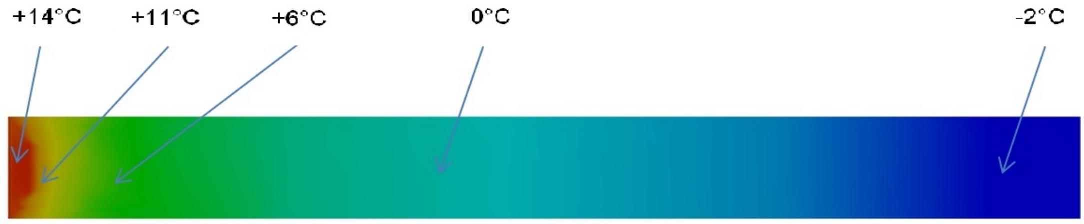

c)

Fig. 5. FEM of temperature fields in continuous and uniform structure at –10°C ambient temperature after 20 minutes of its operation: a – physical configuration of the structure; b – temperature fields in the internal cavity of the structure; c – temperature fields in longitudinal section

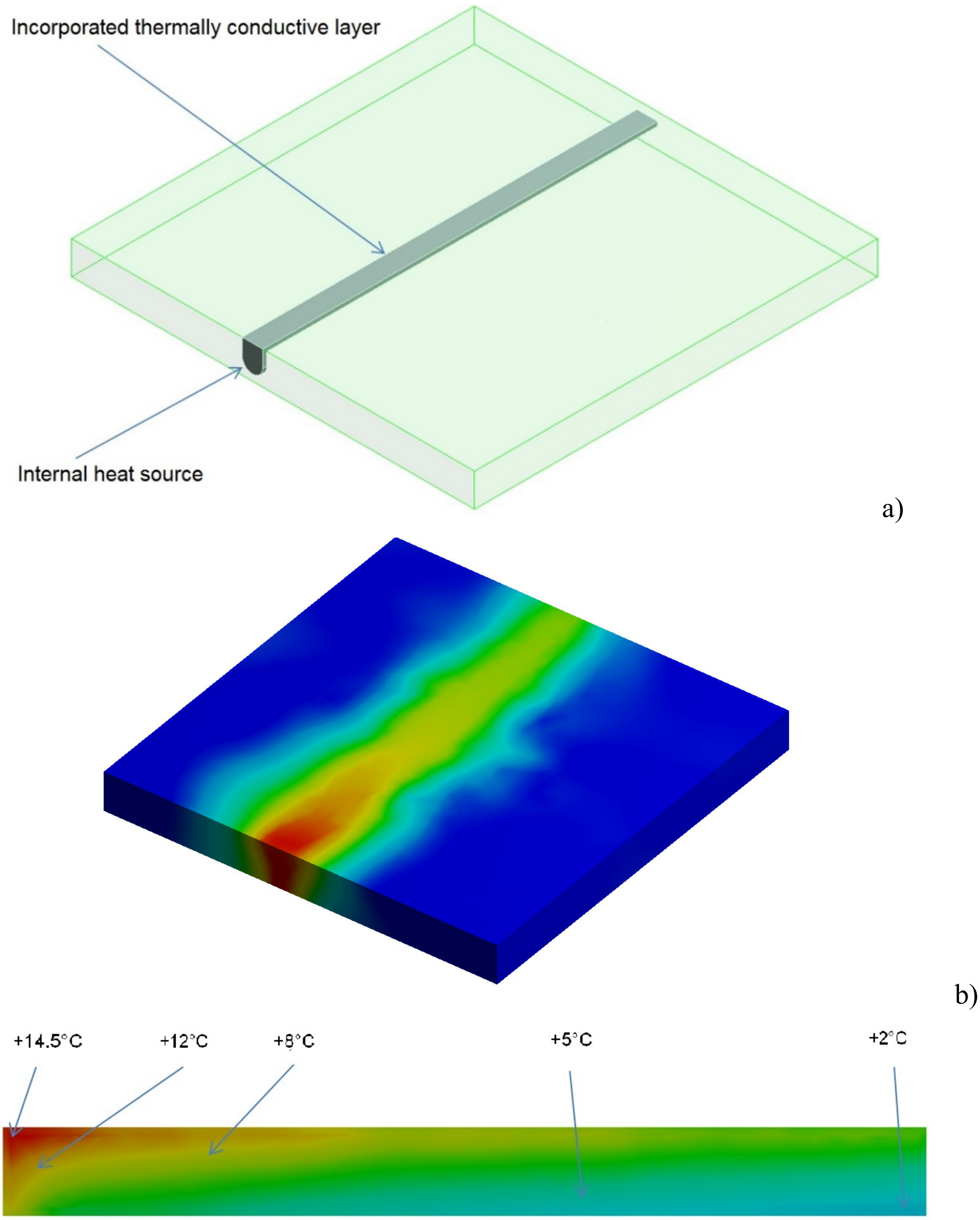

Fig. 6. FEM of temperature fields in multilayered structure at –10°C ambient temperature after 20 minutes of its operation: a – physical configuration of the structure; b – temperature fields in the internal cavity of the structure; c – temperature fields in longitudinal section

Conclusions

Summing up the results, it can be concluded that the mechanical strength of the multilayered wall structure was not a limitation for its use in housings of X-ray flat panel detectors. And the increase in its weight and size was insignificant as compared to the continuous wall structure.

It was demonstrated that the temperature fields in the housing with the multilayered structure were characterized by higher temperatures in areas nearby the heat conductors, thereby providing more efficient heating of the appropriate assembly components than in the wall structure without incorporated heat conductors. This is because the heat distribution inside an ordinary wall structure was uniform, and all the assembly components were subjected to heating, including those that needed no heating.

This research has clearly shown that the housing wall structure comprising heat conductors made of thermally conductive plastic and obtained *via* 3D printing technology, provided the appropriate mechanical strength and temperature field distribution within that wall structure. As a result, the efficient thermostat control was achieved for the digital X-ray flat panel detector to be used in extremely low temperature conditions.

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