

## Article

# The Role and Place of Traditional Chimney System Solutions in Environmental Progress and in Reducing Energy Consumption

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**Abstract:** Buildings, energy, and the environment are key issues facing construction around the world. The energy efficiency of buildings is a key topic when it comes to reducing the world's energy consumption, releasing harmful gases, and global climate change, as they consume about 40% of the world's energy supplies. Heat losses in buildings reduce the energy performance of buildings and are basically important to them. In the paper, the authors focus on the main problems related to heat losses generated by chimney systems, which are inseparable equipment of building structures, resulting in lower energy efficiency and, at the same time, technical efficiency and durability of the building partitions themselves. Authors present thermal imaging with its contribution to the detection of heat losses, thermal bridges, insulation problems, and other performance disturbances, and then verifications using appropriate simulation models. The mathematical apparatus of artificial neural networks was implemented to predict the temperature distributions on the surfaces of prefabricated chimney solutions. In Europe, we can often find a large building substance equipped with traditional chimneys, which disrupts the current trend of striving to reduce energy consumption, especially that derived from fossil fuels. Speaking of energy-efficient buildings, one should not ignore those that, without additional security and modern installations, are constantly used in a very wide range. Therefore, the article deals with an essential problem that is not perceived in design studies and during the operation period as having a basis in incorrect architectural solutions and which can be easily eliminated. It concerns the cooling of internal partitions of buildings on their last storeys, in places where chimneys are located, regardless of their function. The authors of the paper decided to take a closer look at this phenomenon, which may allow the limiting of its effects and at the same time reduce its impact on the energy performance of technologically older buildings.

**Keywords:** efficiency; operational safety; gravity; ventilation; natural ventilation



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## 1. Introduction

Energy is one of the most essential material needs of human life. Its production, as any human activity, is accompanied by the environment, and a side effect of this is the emission of unused energy and pollution into the environment, especially when its source is coal and other fossil fuels [1]. Chimneys and combustion installations (in various forms) have accompanied man for thousands of years. Their original function was exclusively to carry away exhaust fumes from heated rooms.

Nowadays, the chimney flue and ventilation systems perform more complex functions, although the basic one—safe discharge of smoke fumes and used and humid air—remains unchanged. Modernisation of heating device construction, aiming at the highest possible efficiency of boilers, common access to various kinds of liquid and gas fuels, and changes in combustion technology of solid fuels have resulted in changes in the parameters and composition of combustion products [2–7].

Incorrectly designed chimneys, made of improper materials, functioning without inspection, maintenance, and repairs required by law are the cause of many accidents and tragedies. Every year, many users suffer from carbon monoxide poisoning, and the losses caused by fires in buildings and structures are estimated to be in the tens of millions of euros [7–10]. It is common to use chimneys without chimney sweeps and to disregard the above-mentioned obligation to periodically inspect and clean these installations or to make arbitrary changes and alterations [11]. Nowadays, they are both technological installations and at the same time responsible constructions. Therefore the European regulations place them among the construction devices or constructions subject to special supervision, regardless of their function. This is intended not only to control the technical performance of the chimneys themselves but also the extent of their impact on people and their surroundings [12–15].

Apart from the safe flue gas discharge and exchange of air in the rooms, the construction of chimneys should also take into account the uncontrolled migration of thermal energy through their walls at the chimney—building interior border—chimney—external environment border, which is connected with the constant physical and chemical processes taking place here. Chimney walls are complete partitions comparable to the external walls of buildings and constructions (including energy-saving buildings), through which heat and moisture exchange constantly occurs, not only during heating periods. Their improper design will not only cause increased CO<sub>2</sub> emissions into the atmosphere but also heat energy, forcing users to heat their buildings additionally. It is difficult to find innovative solutions for so-called solar chimneys in new design studies. The difference between traditional and solar chimneys lies in the fact that in the latter ones, at least one of the walls (mainly the southern wall) has a transparent layer (covering), which significantly intensifies the ventilation draught [16] so that the chimney outlet is not so intensely cooled as in traditional solutions [17–19]. The difference between traditional and solar chimneys consists in the fact that in the latter one, at least one of the walls (mainly the southern wall) has a transparent layer (casing), which significantly intensifies the ventilation draught, and the chimney outlet will not be so intensely cooled as in traditional solutions [20–22].

The authors of the article, recognising chimneys not only as devices highly responsible for the functional safety of buildings, proposed that they should also be considered as responsible building partitions, equivalent to external building partitions, which should not be routinely selected, but each time designed as a responsible building element. These barriers should effectively protect both the interiors of buildings and chimney flues from uncontrolled loss of heat, which could be used for other purposes. The issue of the efficiency of the operation of traditional flue pipes as well as the impact on ecology and the reduction of energy consumption has been addressed in numerous studies, e.g.: [1,23–31]. In this paper, some example simulations are included to show the possibility of improving the thermal protection of the partitions described above and in this paper.

### *1.1. Types of Chimney Construction*

Just as in the past, wood and coal are the most commonly used fuels, so the traditional materials used to make chimneys were building ceramics and, for about 120 years, silicates and cement (concrete), in the form of bricks, pipes, ceramics, silicate, and even cement and asbestos fittings. Nowadays, other materials such as stainless or acid-resistant steel or acid-resistant ceramics are increasingly used. In modern heating devices, low flue gas temperatures are the reason for condensate condensation (sometimes in considerable amounts), which, due to its composition, has a destructive influence on the chimney, lowering its technical efficiency and shortening its service life.

Mineral wool or ceramic cladding with a U-value of approximately 0.4 W/m<sup>2</sup>K is used for chimney insulation. The insulation should provide the walls of such ducts with the required protection against excessive and rapid cooling, especially outside the building. There is currently a range of insulation materials available on the building market that can be used to reduce heat loss in compartments. The purpose of such insulation is the

aforementioned protection against uncontrolled cooling of air and flue gases, which in the case of a negative-pressure chimney will result in the reduction of the chimney draft force effectiveness, and thus will reduce its technical efficiency and at the same time reduce the heat emission to the nearest surroundings. This is particularly important for chimneys at risk of soot ignition. To achieve the required temperature reduction on the jacket of high temperature insulated chimneys (operating temperature of 600 °C), multilayer insulation is increasingly used. The first layer of insulation (on the duct side) consists of ceramic material resistant to high temperatures (even above 1000 °C), the second one of special mats or fittings with a thermal resistance above 500 °C. A chimney made in this way is safe for the environment, both in terms of fire and to protect against the possibility of burns in case of contact with the cladding [32–34].

When analysing the operating conditions of chimney systems in Central Europe, they have to be considered as highly “specific”. The condition of smoke and ventilation chimneys and flue gas installations is assessed highly critically in chimney sweeping reports. This is not helped by legal loopholes in the chimney sweeping trade, including the performance of acceptance and inspection functions, which should be carried out by authorised masters. Chimney systems, especially external chimneys, should be adapted to the climate zones in which they are installed. The climate typical of a given area influences both the type and parameters of materials used (e.g., insulation) and the chimney’s operation characteristics. From the point of view of the work of heating installations, the climate of temperate zones are characterised by both extremely low (below −25 °C) and high temperatures (above 25 °C), a very long heating period (often reaching 8 months) and under such conditions, the chimney system must always work properly.

Internal ventilation chimneys, flue gas chimneys, and still smoke chimneys are an integral part of buildings and structures, and therefore their use is governed by building regulations. Therefore, for chimneys, both statutory provisions [35–40] as well as executive regulations related to the use of energy equipment, especially in relation to gas and oil installations, apply. In Europe, intensive efforts are being made against the legal background to combat environmental pollution, as exemplified by the adoption on 10 January 2007 by the European Commission of the energy and climate change package as the basis for a new energy policy for Europe (European Energy Policy, Brussels, 10.1.2007 COM(2007)). Its main strategic objective was to achieve a reduction in emissions of greenhouse gases and to increase the share of renewable energy in the total EU energy balance from less than 7% in 2006, as well as to reduce the total consumption of primary energy by 20%, compared to 2006. Energy production on an industrial scale, as with other industrial sectors, is subject to stringent environmental requirements for the introduction of the best available technologies (BAT) and the most effective means of removing pollutants from exhaust or process gases. This results in a significant reduction in pollutant emissions from industrial sources. On the other hand, the least “disciplined” sector of energy production from sources below 50 MW is the biggest shareholder of global, both worldwide and national, emissions of pollutants. Therefore, this sector has been subject to specific actions in the EU aimed at technological and legislative disciplining to increase the energy efficiency of the energy production techniques used and to reduce their environmental impact. In the Clean Air of Europe (CAFE) Thematic Strategy (COM(2005)), developed within the framework of CAFE, special attention was paid to installations with a capacity <50 MW, i.e., the so-called small combustion plants, for which there are no EU regulations, especially installations for the combustion of solid fuels producing useful energy for heating individual households and preparing domestic hot water. One of the legislative acts concerning EU measures aimed at reducing primary energy consumption, among others in households, is [41,42] establishing general principles for setting eco-product/eco-design requirements [43] for energy-using products. Due to the dominant role of energy cost in the life cycle costs of these appliances, the Directive emphasises the promotion of energy-efficient appliances. In the case of boilers, cookers, fireplaces, the main objective of the Directive is on the one hand to harmonise the regulations on appliance design (the aim is to avoid distortions

in the free movement of products), and on the other hand, to induce manufacturers to produce appliances characterised by high efficiency of converting the chemical energy of fuels into useful energy—space heating, the preparation of domestic hot water, the preparation of meals, and more environmentally friendly products. Environmentally friendly products are not only from the point of view of low emission of pollutants, optimally low consumption of energy resources to produce useful energy, but also low unit consumption of materials to produce particular types of cookers/boilers/fireplaces and the possibility of recovery/recycling of materials or safe disposal at the end of operation. In 2007, the European Commission started work on establishing eco-design requirements [44] for low power combustion installations—boilers/furnaces/chimneys fired with solid fuels (coal and biomass). These actions are coherent with the assumptions of the Green Paper of the European Strategy for Sustainable, Competitive and Secure Energy and for Improving the Competitiveness of the Economy [45].

It should also be noted that irrespective of EU and national legislative measures, there is also an increase in the knowledge and awareness of the consumer—users of solid fuel combustion systems in individual buildings—which is reflected in the growing demand for high-quality equipment, especially in terms of high energy and environmental efficiency, high comfort of operation, and low operating costs. This, in turn, has resulted in the recent development of modern designs of heating devices fired by solid fuels, coal, and biomass, especially of wood origin, and both fireplaces and boilers. The greatest progress in the development of technologies used in heating devices has occurred in boiler designs fired by coal and, in recent years, also by biomass, especially in the compacted form of pellets. Considerable progress can be seen in the construction of fireplaces. In the case of industrial and professional power engineering, strict environmental protection requirements impose the use of the best available technologies for electricity and heat production (BAT technology). This results in a significant reduction in pollutant emissions from industrial and professional sources. On the other hand, the production of heat, using coal as a fuel, in dispersed sources—in the municipal sector, single-family housing, public utility buildings, agriculture, forestry, fisheries, dispersed military units and industrial plants, everywhere where it is uneconomical to apply highly efficient installations for flue gas cleaning and where outdated central heating boiler installations and household furnaces are used and where “bad practice” of burning non-sorted coals is applied, as well as burning and co-combustion of municipal waste—causes very high emissions of pollutants to the atmosphere.

This does not, however, solve the problem of improving the energy efficiency of existing buildings, which in fact require immediate intervention to improve efficiency and to provide the solutions sought by the authors during their research of historical and contemporary buildings made using older technologies. The main objective of this research is to determine the causes of corrosion degradation of building partitions related to the functioning of ventilation chimneys, as well as to assess the current extent of damage and provide methods or ways to remove the causes and remedy the effects [46].

### *1.2. Requirements for Flue Pipes*

External chimneys, from the point of view of building regulations [16,35–40,42], are classified as either structures or equipment and are fully subject to building regulations. During chimney testing, the safety of the chimney’s impact on both combustible and load-bearing elements of the building structure is checked. The manufacturer declares the minimum distance between the chimney and combustible elements under normal operating conditions, regardless of the function of the flue pipe. The temperature at the declared distance from the combustible elements (100 mm in the example) must not exceed 85 °C. Of course, safe distances of 100 or 200 mm (at a flue gas temperature of 450 °C) from combustible parts are only achievable with insulated chimneys. For single-walled uninsulated chimney liners, the distance to combustible parts should not be less than 450 mm. During the tests carried out in an accredited laboratory, other



parameters declared by the manufacturer are also verified, such as: thermal resistance of chimney insulation (double-walled chimneys), resistance to atmospheric conditions, flow resistance through individual chimney elements, the durability of fixed elements (supports, brackets, consoles).

When applying for the “CE” mark for insulated chimneys, the manufacturer shall specify the parameters of the thermal insulation used. The thermal insulation of insulated chimneys must have the following characteristics:

- Be completely resistant to the stated flue gas temperatures.
- Have an adequate thermal resistance coefficient, which guarantees the maintenance of the safe temperature of the external jacket at specified flue gas temperatures, as well as the maintenance of the required operating parameters at low ambient temperatures (minimisation of condensation).

Good insulation with a thermal resistance coefficient at temperatures around 250 °C of between 0.4 and 0.6 W/m<sup>2</sup>K should be resistant to short-term exposure to high temperatures, such as a soot fire, i.e., 1000 °C. The standard does not specify the thickness of insulation that should be used for chimney insulation.

According to the standard [43], the resistance of insulated chimneys is tested mainly for rainwater tightness. The tightness of the connections of individual elements is controlled by placing the chimney in a special rain chamber. The tightness is measured by examining the mass of insulation before and after the test in the rain chamber. An increase in the mass suggests a lack of jacket tightness and discredits the chimney.

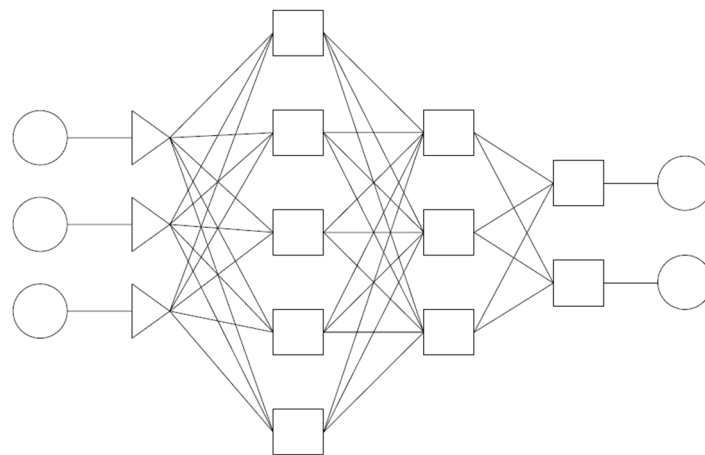
Prefabricated chimney systems lose draught and cause the cooling of the top floor, which is a determinant of significant heat loss and a drop in the energy efficiency of the entire building. The consequence of this phenomenon is the condensation of moisture caused by the temperature difference, which is an excellent environment for the development of fungi and moulds, significantly affecting the comfort of use of the building [19,39,40,46–49].

## 2. Materials and Methods

The energy efficiency [47] of chimneys can be verified by a number of tests, i.e., thermal imaging tests, temperature measurement, pressure measurement. Thermal imaging tests are a research method, which consists of remote and noncontact evaluations of the temperature distribution on the surface of the tested object [50]. The working principle of the method is based on the registration of the distribution of infrared radiation emitted by any body whose temperature is higher than absolute zero and the transformation of this radiation in a detector into visible light. The resulting colour thermal image is a thermogram, indicating on a colour scale the level of the recorded surface temperature. If thermal images are taken from the outside during the cold season of the year (heating period), places on the external surface with an increased temperature correspond to less well-insulated areas of the partition, while a low surface temperature can usually indicate good insulating properties of the partition. The opposite situation will occur if photographs are taken of the internal side. Places with a lower surface temperature indicate deterioration of the insulation properties. This method is becoming increasingly used in the construction industry in activities classified as thermal (energy) diagnostics of buildings and their technical equipment. Using thermographic measurements, it is possible to detect not only defects in the thermal insulation of external partitions, including various types of thermal bridges, but also leaks, creating conditions for heat flow as a result of intensified air infiltration. [48]. The energy efficiency of solid fuel combustion systems, especially of traditional design, is relatively low and does not exceed 50% on average per year. It also results in excessive consumption of coal and biomass—higher than the demand for useful energy in flat, single-family houses or public utility buildings.

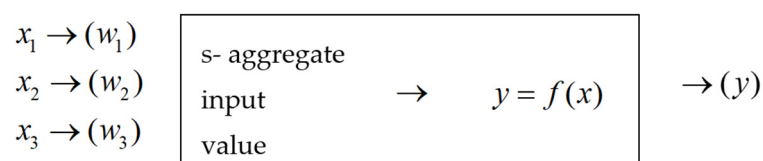
In general, it can be said that a neural network is a simplification of the brain structure diagram. The basic component of an artificial neural network is the processing element. It is a specific model of real cells that are part of the nervous system, responsible for processing and analysing information in the human body. The actual nerve cell can be

treated as a biological information processing system. The information introduced through the inputs (dendrites) is processed inside the cell. The processed signal is sent via the axon to subsequent cells. Each neural network consists of a large number of elements with the ability to process information (neurons), which are associated with each other by connections with specific parameters (weights), which change during the learning process. The schematic diagram of the artificial neural network structure is shown in Figure 1, according to which it can be stated that nowadays, neural networks have a layered structure, where the following layers are distinguished: input, output and hidden layers [51–53]. One of the available features of STATISTICA—unidirectional MLP multilayer network is the software that is based on the backpropagation error algorithm used for the prediction in this paper.



**Figure 1.** Diagram of an artificial neural network based on [51–53].

The neuron has a finite number of inputs, to which the inputs are given as:  $x_1, x_2, \dots, x_n$ , with associated weights:  $w_1, w_2, \dots, w_n$ . The process initiated by the input data is reflected by basic information occurring inside the neuron. The first is the determination of the aggregated input value and is carried out using an aggregating function, also known as the “postsynaptic potential function” (PSP function). The second process consists in determining the output value of the neuron, for which the activation function (transition function) is responsible. In general, these processes can be represented by the diagram in Figure 2 [51–54].



**Figure 2.** Schematic of the artificial neural network model, reflecting the processes occurring inside the neuron.

The aggregated input value of a neuron becomes the parameter of the activation function of that neuron. Common activation functions include linear, logistic, hyperbolic, exponential, sinusoidal, and Gaussian equations. The basic feature of neural networks is their ability to self-organise and adapt to changing conditions, which results in the possibility of selecting weights that can change in the learning process. SSN algorithms (artificial neural networks) are a tool perceived as informative, albeit learning, as they have the ability to adapt the stock of knowledge they possess to the possibility of its dynamic change. This is a fundamental characteristic, as this ability determines the possibility of self-learning, which significantly speeds up the execution of calculations. Learning consists of changing the coordinates of neurons so that they follow a pattern consistent with the structure of the data analysed. Therefore, the calibration of the phenomenological (abstract)

model created by the network consists of an adequate selection of weights in the learning process. During learning, some connections (weights between neurons) become more important, and some do not participate in solving the problem (this could be compared to the disappearance of connections in the brain), so it is possible to determine which variables are important in terms of solving the problem. The structures presented can be used in many areas of science. Many examples can be cited, such as: electronic circuits research, psychiatric research, sales forecasting, biological research, interpretation, machinery repair, planning, production problems analysis, industrial processes control.

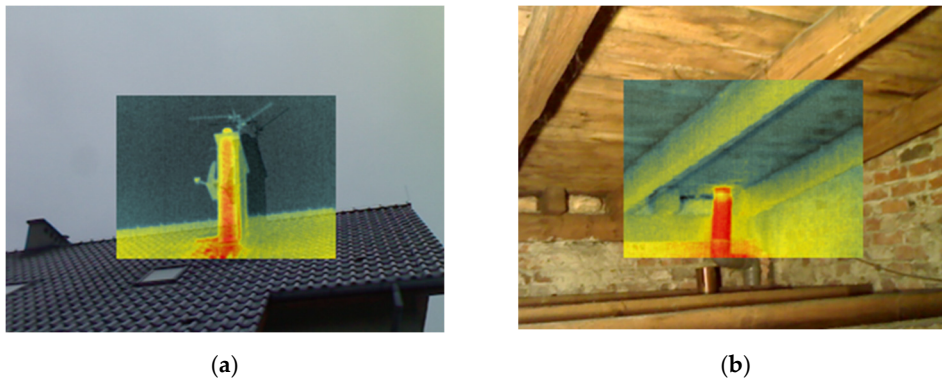
### 3. Results

The aim to achieve the highest level of energy efficiency in building envelopes and thus also in entire buildings, aimed at the development and implementation of new and modern techniques, is the result of technological progress and at the same time sustainable development. This also makes it possible to reduce the extraction and consumption of fossil fuels. The authors have analysed a very large number of types of chimney flue, and the main problems are presented in the paper.

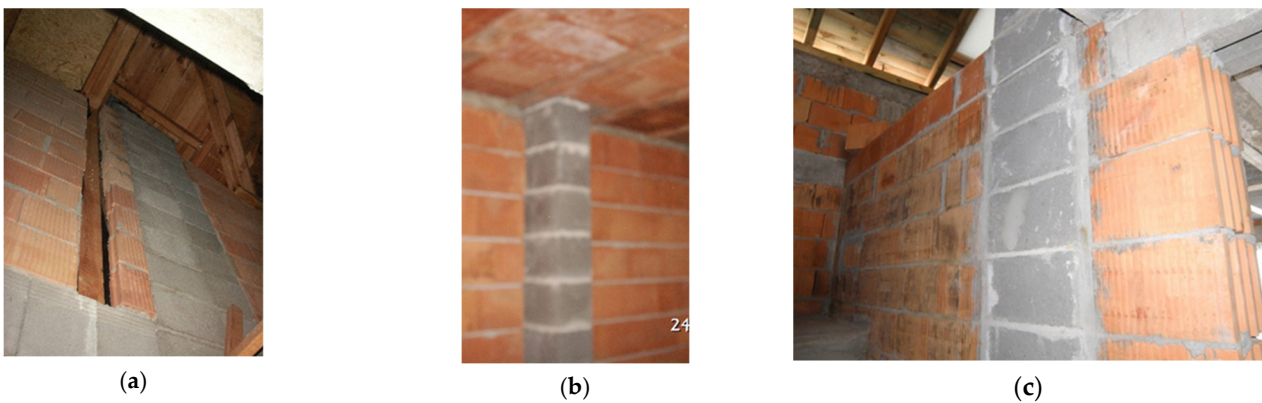
Nowadays, we should also ask ourselves a question: when talking about energy saving, do we also mean very much cubic building resources exploited for many years, which also need such modern solutions? Unfortunately, they are still at the end of the queue for modernity. The existing housing stock, equipped with traditional brick chimneys or newly installed system solutions, is not only a problem for the environment but also for the users of these buildings. Problems are created not only by the emission of pollutants into the atmosphere but also by the cooling of building envelopes of the last storeys of buildings, such as flats and attics. The location of chimney flues on the top floors of buildings often creates very significant operational problems, including hygienic and sanitary ones. This problem initially manifests itself in the form of moisture condensing on the surfaces of external and internal partitions. In a later stage, local discolourations appear, which in the final stage turn into foci of microbiological threats due to the development of moulds on cooled fragments of thin-walled chimney ducts. Additional thermal bridges (linear and surface ones) often occur in places where chimneys are led above roofs, above heated floors. This phenomenon cannot be fully eliminated by applying common solutions, but its effects may be considerably limited. Intentional or unintentional, periodical switching off of parts of the storey, premises or only single rooms or inefficient or even inefficient ventilation may also turn out to be an important element in generating heat losses. The authors tried to present such cases on the basis of observations and own research verified by simulation models.

The cases shown in Figure 3 are quite common in construction practice, which may indicate a disregard for this problem, poor knowledge of designers, and lack of awareness of building owners and managers. Such situations not only generate higher operating costs of buildings but, above all, are the cause of significant emissions into the atmosphere due to incomplete combustion of fossil fuels. In addition, the cooling of chimney walls and adjoining walls occurs, which contributes to their slow but progressive chemical and biological degradation due to the deposition of aggressive substances on them. Such situations are also a direct source of microbiological risk for the inhabitants of the top floors of buildings.

In Europe, modern chimney systems are still being integrated into the existing walls of buildings, thus compromising their spatial rigidity. According to the manufacturers' claims, chimney risers should be independent and self-supporting structures, but in reality they are subjected to additional loads by being "glued" tightly into existing structures (Figure 4).



**Figure 3.** Non-thermally insulated flue pipes: (a) in the part above the roof, (b) in the attic space.



**Figure 4.** Non-thermally insulated chimney flues: (a) in the part above the roof, (b,c) in the attic space.

These chimneys, both in the attic space and above the roof, do not have layers protecting against excessive heat loss, and they cool down quite quickly. This is one of the reasons for chimney draught deceleration and, at the same time, the reason for the dampening of the internal partitions of buildings on the last floors and the development of harmful moulds. As already mentioned above, both walls and chimneys may be subject to faster wear and tear or damaged by corrosive degradation, which reduces their technical performance (Figure 5).

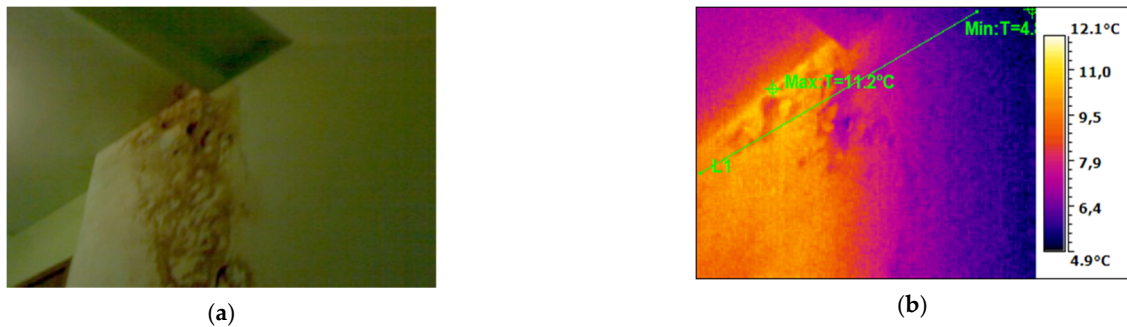


**Figure 5.** Consequences of inadequate protection of external and internal chimney walls (a,b) elevation, (c) inside.

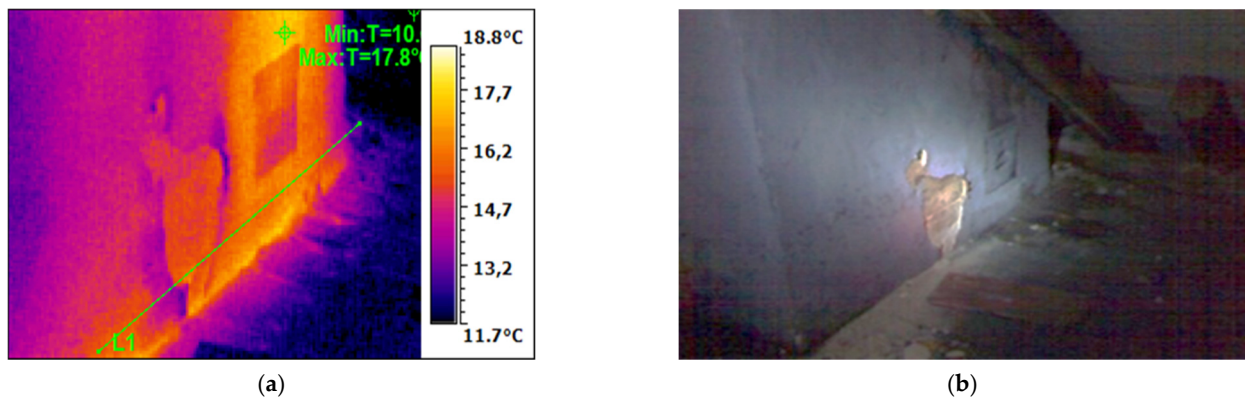
This can lead to serious mechanical damage to chimneys and even entire buildings.

The variation of the temperature fields on the chimney wall is shown in Figures 6 and 7, diagrams of temperature distribution (along the line running directly under the ceiling). As the walls of the top floors are additionally heated here, and thus the rooms are heated, the heating systems require more thermal energy, which results in a significant increase in fuel consumption.





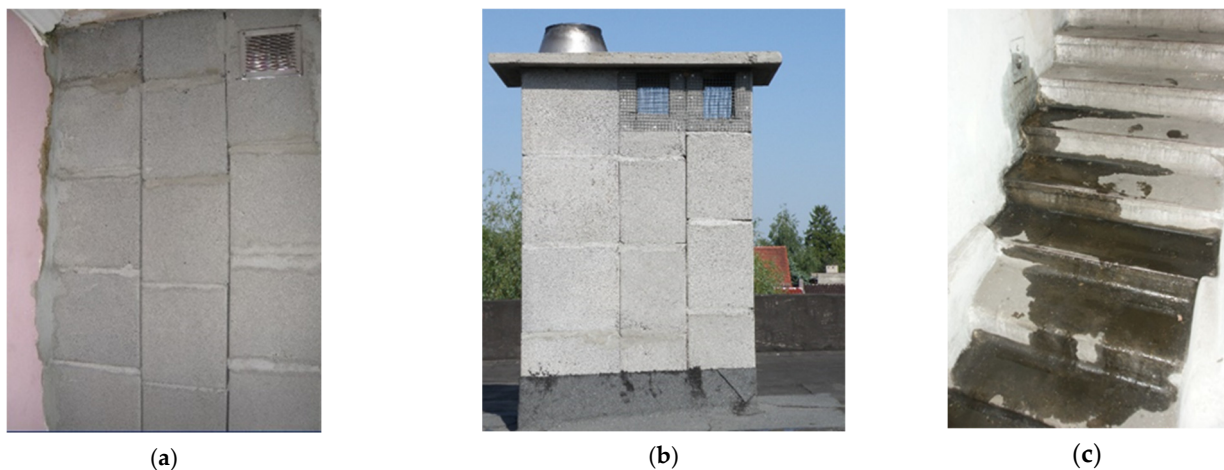
**Figure 6.** Thermal (a) image of the temperature distribution on the surface of the chimney wall in visible light (b).



**Figure 7.** Thermal (a), and visible light (b) images of the chimney wall in the attic space (at the inspection grille).

Temperature distribution on the surface of a chimney located in an attic space containing smoke and ventilation ducts (Figure 7).

Figure 8 shows a certain stage in the modernisation of a single-family building through the introduction of prefabricated system chimneys. The effect of their inadequate installation has already been noticed in the winter period on the first floor of the building and in the basement, at the clean-out opening.

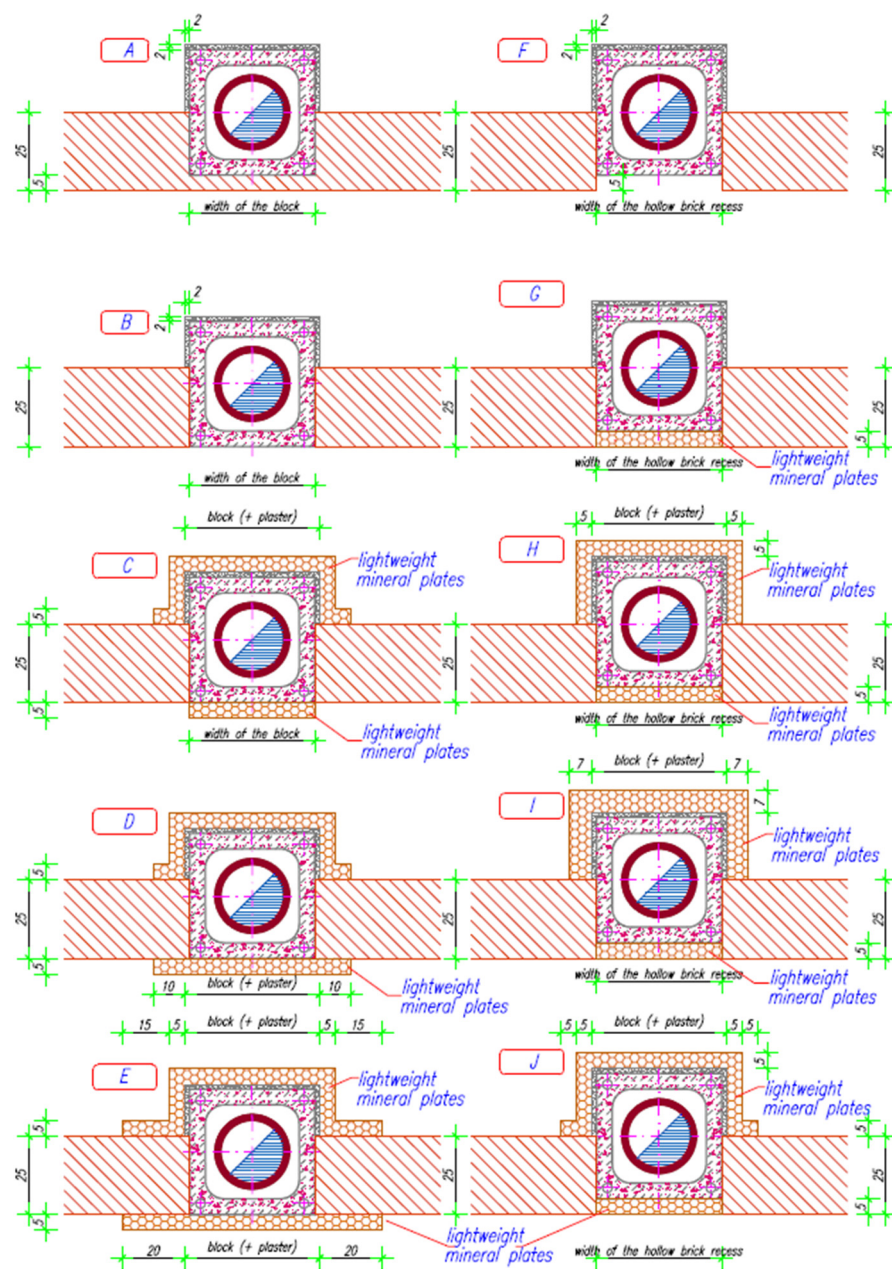


**Figure 8.** Prefabricated ventilation flue pipes: (a) inside the building, (b) above the roof, (c) condensation leakage in the basement through the clean-out opening.

It is difficult to agree with the position that our future will be based on the continuous improvement of chimney systems in modern construction (including passive construction), increasingly limiting carbon dioxide emissions into the atmosphere when a significant proportion of older buildings have not kept up with “this” modernity. Despite the incorpo-



ration of new technologies, this is done in an incompetent manner, inconsistent with the intentions of the manufacturers of these products and at the same time inconsistent with sustainable development. Therefore, it is necessary to develop modernisation and repair solutions for the existing buildings not only in the form of reinforcement of traditional masonry constructions [55] or analysis of their dampness [55], but also methods which would make it possible to ensure the highest possible level of chimney draught, prevent local heating and cooling of internal partitions (walls) on the top floors, and, at the same time, ensure efficient ventilation and comfort of rooms. This would eliminate unnecessary heating or cooling of such floors, and thus reduce energy consumption and prolong the life of the buildings and their partitions. To confirm the above thesis, a simulation has been carried out for one flue pipe, built into a wall without insulation and with insulation in several variants (Figure 9), based on the experiments presented in [55–57].



**Figure 9.** Design models of chimney structures adopted for simulation analyses without insulation (A,B,F) and with insulation (C–E,G–J).

### 3.1. Starting Assumptions for Thermal Calculations Results

For the calculation of the surface temperature [58] it is recommended to take the following values for the heat transfer resistance of internal surfaces:

- Upper part of the room:  $R_{si} = 0.25 \text{ m}^2\text{K/W}$ .
- Lower part of the room:  $R_{si} = 0.35 \text{ m}^2\text{K/W}$ .
- With significant shielding of the wall surface by objects such as furniture:  $R_{si} = 0.50 \text{ m}^2\text{K/W}$ .

In the case studied, significant shielding of the wall surfaces was assumed:  $R_{si} = 0.50 \text{ m}^2\text{K/W}$ . For the calculation of the surface temperature, the magnitude of the heat transfer resistance on the external surfaces was used:  $R_{se} = 0.04 \text{ m}^2\text{K/W}$ . The design temperatures of the heated rooms have been assumed based on [35] as characteristic values for Central and Eastern Europe. For this analysis, the values of internal temperatures are summarised in Table 1.

**Table 1.** Values of internal temperature.

Design Temperatures	Purpose or Use of Premises	Examples of Rooms
+20 °C	– intended for permanent residence of uncovered people who do not continuously perform manual labour	living rooms, anterooms, individual kitchen with gas or electric fires, offices, meeting rooms
+24 °C	– intended to be dismantled – intended for human habitation without clothes	bathrooms, changing rooms, washrooms, showers, swimming pool hall, doctor’s office, undressing, baby and nursery rooms, operating theatres

Simulation calculations have been carried out for the rooms of the last storeys of residential and office buildings using partition models, with the following assumptions:

- $t_i = + 20.0 \text{ }^\circ\text{C}$  (rooms)
- $t_r = + 4.0 \text{ }^\circ\text{C}$
- $t_w = - 5.0 \text{ }^\circ\text{C}$

where:

$t_i$  means the indoor air temperature,

$t_r$  means the temperature inside the tube (ceramic insert),

$t_w$  means the temperature inside the ventilated space in the counterflow mode.

In the following part of the study, the temperature distribution in partitions containing chimney flues, the indication of the location of the thermal bridge with the lowest surface temperature value with its magnitude, and the layout of heat flux density lines are presented in the calculation models. To avoid surface condensation, several options were considered for insulating the locations where prefabricated system chimney flues will be installed in terms of their shape, extent, and location.

For simulation calculations of heat flow in chimneys, a square cross-section of the chimney section has been assumed instead of a round one and a square cross-section of the prefabricated protective element is often used in practice (Figure 10). This assumption is the most correct from the point of view of correctness of calculation, more so as it complies with the standard [59], where in Appendix B4 [59] it is written, “For a nonrectangular air void the thermal resistance is assumed to be equal to the resistance of a rectangular void with the same surface area and the same ratio of sides”. These were the assumptions made by the authors of this paper for their calculations. The above-mentioned variants of the location of the flue pipe were analysed in terms of heat transport, taking into account the different locations of the thermal insulation layer made of lightweight mineral panels (5 and 7 cm thick), characterised by a thermal conductivity coefficient of  $\lambda = 0.045 \text{ W/mK}$ .

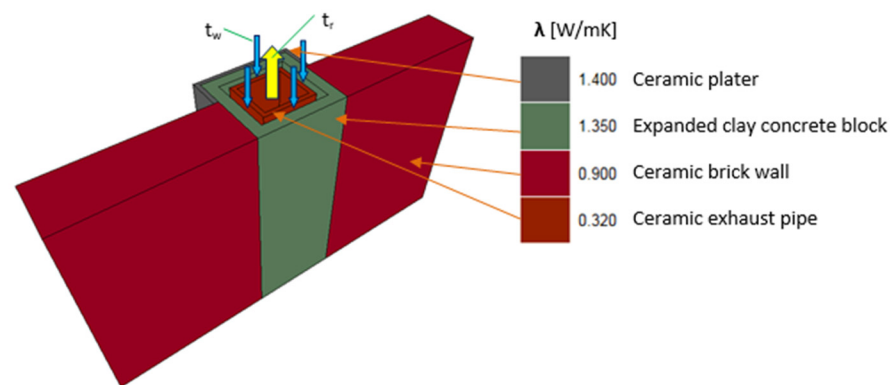


Figure 10. Calculation model.

The phenomenon of “overcooling” or “overheating” of walls on integrated traditional system chimneys is rarely recognised by architects and builders. The diagrams in Appendix A, Figures A1–A10 show how important this problem can be, especially for partitions that can lead to excessive heat loss, not taking into account the thermomodernisation of buildings. Increasing the insulation around the chimney flue, even slightly, leads to a significant energy gain.

Figures A1–A10 show the distribution of isotherms and adiabatic heat fluxes in the inner walls of the chimney stack caused by temperature differences. These models are assigned to the cross-sections shown in Figure 10 and presented as a detailed numerical analysis of the distribution of temperature and heat fluxes in the cross-section and at the height of the flue pipes. Figures A1, A2, A6 and A7 has been borrowed from construction practice as they are often used in design solutions and are also executed in this way. Such places of connection between chimney stacks and building walls generate excessive heat loss, creating a network of linear thermal bridges, which also becomes a microbiological threat to the users of the rooms through which the chimneys run. The authors of the article, using models C, D, E, H, I, and J as an example, have tried to show the possibility of limiting heat loss depending on the shape and range of the thermal insulation material.

The scales placed next to the diagrams show the temperature ranges in which particular fragments of chimney walls may be found during their operation and the adiabatic fields of heat streams assigned to them. The lowest models in Figures A1–A10 indicate the locations of the most cooling linear thermal bridges (orange colour). These are places of the smallest wall thickness in non-insulated chimneys and/or places of thermal insulation endings in single- or double-sided insulated chimneys.

This does not mean, of course, that they will consistently reach the extreme values shown above. Nevertheless, even internal partitions of buildings, which may be cooled down by introducing into them ventilation, air and fume ducts, or smoke ducts, should be additionally protected with a layer of thermal insulation protecting them against the lowering of temperature to critical values (in cold periods) or against overheating of rooms in the case of fume and smoke ducts.

Even a small layer of thermal insulation, with a low heat transfer coefficient and low diffusion resistance, is able to significantly improve the parameters of the cooled partitions, and thus the entire room. The authors of this article have used the simulation model parameters, which are characterised by mineral thermal insulation panels, ideally suited for insulating partitions from the inside. They are made from a very lightweight variety of cellular concrete and have a very low diffusion resistance ( $\leq 3$ ). Their additional advantage is their low density ( $115 \text{ kg/m}^3$ ); hence they will not be a significant burden on walls and chimneys, both inside buildings and those extending above the roof. Moreover, they are easy to process, have a low thermal conductivity coefficient  $\lambda = 0.043\text{--}0.045 \text{ W/mK}$ . Therefore their thickness will be required to insulate the walls, which will result in the reduction of the usable area of the room only slightly.

The authors of the article analysed many architectural design solutions and did not find that any of the designers raised such a topic. On a global scale, the problem of unnecessary heat loss may turn out to be a very serious one, which can be very easily eliminated by raising the awareness of those responsible for building design. It will be enough to implement very simple and at the same time effective solutions, not only to reduce additional heat losses but at the same time improving the chimney draught and a more complete fuel combustion. In every European country, regulations require buildings to be properly maintained and periodically inspected. These obligations are usually incumbent on building managers and owners.

Prior to the thermomodernisation of buildings, energy audits should always be prepared, in which the issues described in the article should find their permanent place. Thermomodernisation of buildings should also include thermal insulation of such partitions inside the buildings, regardless of the adopted method of thermomodernisation of the whole building.

Table 2 summarises the results of the calculations carried out for surface temperatures in relation to the “dew point” temperatures corresponding to the indoor relative humidity of 45%, 55%, and 75%. The calculated values of the surface temperatures of partitions placed in columns 4 and 5 should be higher by at least 1 °C than those placed in column 3.

**Table 2.** Temperature comparison for  $t_i = +20$  °C and different  $\varphi$  from 45% to 75%.

Calculation Scheme	$t_s$ (°C)			Surface Temperature Side “A”			Surface Temperature Side “B”		
				$t$ (°C)			$t$ (°C)		
				$t_i = +20$ °C $\varphi = 45\%$	$t_i = +20$ °C $\varphi = 55\%$	$t_i = +20$ °C $\varphi = 75\%$	$t_i = +20$ °C $\varphi = 45\%$	$t_i = +20$ °C $\varphi = 55\%$	$t_i = +20$ °C $\varphi = 75\%$
A	7.7	10.7	15.4	+6.0	+6.0	+6.0	+3.0	+3.0	+3.0
B	7.7	10.7	15.4	+2.0	+2.0	+2.0	+3.0	+3.0	+3.0
C	7.7	10.7	15.4	+5.0	+5.0	+5.0	+11.0	+11.0	+11.0
D	7.7	10.7	15.4	+11.0	+11.0	+11.0	+11.0	+11.0	+11.0
E	7.7	10.7	15.4	+13.0	+13.0	+13.0	+13.0	+13.0	+13.0
F	7.7	10.7	15.4	+2.0	+2.0	+2.0	+3.0	+3.0	+3.0
G	7.7	10.7	15.4	+11.0	+11.0	+11.0	+3.0	+3.0	+3.0
H	7.7	10.7	15.4	+11.0	+11.0	+11.0	+9.0	+9.0	+9.0
I	7.7	10.7	15.4	+11.0	+11.0	+11.0	+9.0	+9.0	+9.0
J	7.7	10.7	15.4	+11.0	+11.0	+11.0	+11.0	+11.0	+11.0

The above data and examples of thermal insulation should not be treated as a form of universalisation of solutions to the example of a few examined cases but as an indication of the directions for further research and implementation. Thinner and improperly insulated walls of chimneys on the last storeys and in attics (regardless of their function) may become the cause of excessive, unpredicted heat loss and, at the same time, degradation of building partitions. The reason for this will be the intensive movement of air and exhaust fumes. For the obtained values, the relative error was calculated: humidity = 0.1%. Surface temperature sides “A” and “B” 0.2%,  $t_s$  0.1%. Based on the obtained error values, the significant digits in Tables 3 and 4 were removed. As mentioned above, each case of thermal bridges should be anticipated and considered individually. This applies not only to the location of chimney flues on the top floors of residential and public buildings.

**Table 3.** Summary of data for analysis.

Humidity	Calculation Scheme	$t_s$ (°C)	Temp. "A" Side Surface	Temp. "B" Side Surface
45	A	7.7	6	3
45	B	7.7	2	3
45	C	7.7	5	11
45	D	7.7	11	11
45	E	7.7	13	13
45	F	7.7	2	3
45	G	7.7	11	3
45	H	7.7	11	9
45	I	7.7	11	9
45	J	7.7	11	11

**Table 4.** Temperature values for prediction.

No.	Temp. "B" Side Surface	Prediction Spreadsheet for Temp. "B" Side Surface (Spreadsheet1)1. MLP 12-5-2
1	3.0	3.0
2	3.0	3.0
3	11.0	11.0
4	13.0	12.9
5	3.0	3.0
	...	
146	11.0	10.9
147	13.0	12.9
148	3.0	3.0
149	3.0	3.0
150	9.0	9.0

In the design studies of new buildings and at the stage of designing modernisation works in the existing facilities (replacement of installations, superstructure, reconstruction, and extension), the issues of migration and excessive heat loss, even in the internal partitions of these facilities, must be taken into account, due to the introduction into all kinds of structures that are not walls, in which any form of forced or gravitational air movement may occur. The issues discussed in the article concerning local cooling of fragments of the internal walls of the last storey are presented with the example of a prefabricated system chimney (produced by one of the leading chimney systems manufacturers in the world), built into the walls of the last storey. Such situations should be anticipated, and, where necessary, preventive measures should be taken in the form of local insulation of chimney walls in the immediate vicinity with a material characterised by high thermal resistance and the lowest possible diffusion resistance. At the same time, it is advisable to inspect such walls in buildings already in use, using thermal imaging cameras, moisture meters, and for the presence of salts and other harmful compounds.

### 3.2. Results of Analyses Carried out Using Artificial Neural Networks

The simulation was made with the help of artificial neural networks, which allowed the prediction of the surface temperature in relation to the "dew point", temperatures corresponding to the relative humidity of indoor air, on the basis of the research results (the results presented above were extended and the prediction database was built). For the



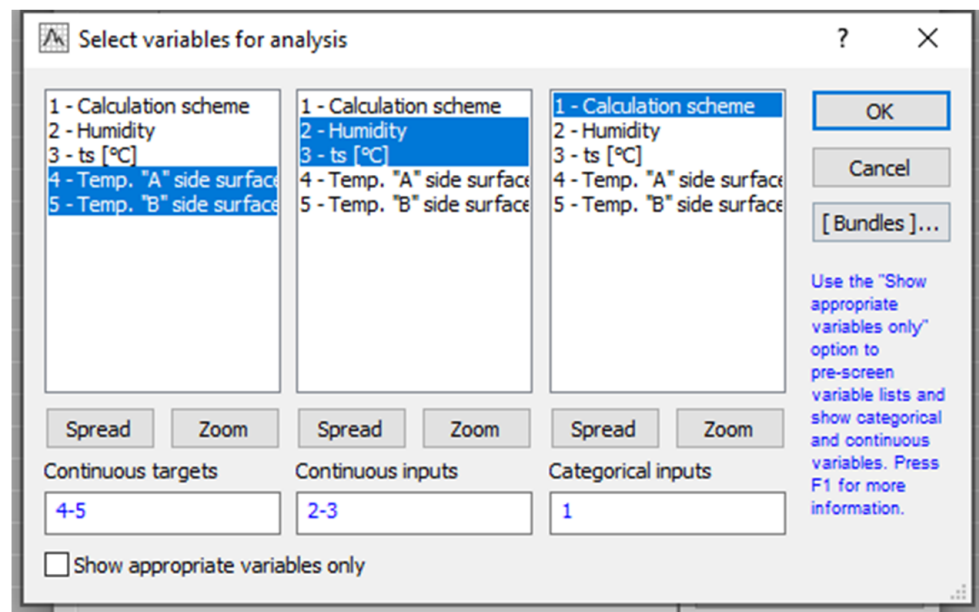
case under consideration (temperature prediction), the problem is defined as an attempt to develop a phenomenological model, determining the relationship between warming and temperature—which is a very complex issue. Neural networks are used when the derivation of the model is impossible. Complicated derived dependencies are insufficiently accurate. Then it is advantageous to use neural networks. The obtained solution will be accurate because the data in the learning set will be the real values of research. As stated above, the neural network follows the pattern given during learning. In the analysed case, the patterns are the results of temperature tests. The data subjected to analysis were divided into sets:

- Teachers (70% of case numbers).
- Test (15% of case numbers).
- Validation (15% of the number of cases).

This division of the data makes the neural network draw 85% of the data on which the learning process occurs and adjusts the weights for the input data (calculation scheme representing the way of warming,  $t_s$  temperature, and humidity). The validation set allows the evaluation (examination) of the predicted temperature with values that the program has not learned or tested. The network was built for forecasting the problem under consideration. It has the following topology:

- Characteristics of the problem: regression; this description of relationships is used to build models showing the actual relationship between the input data (explanatory) and the output variable (explained). In this case, the events are performed in the following sequence: the values of explanatory variables, neural network, the value of the explained variable.
- Number of inputs: 5.
- Network type: multilayer perceptron (unidirectional multilayer networks. MLP networks).
- Learning algorithm: BFGS (variable metric method).
- Number of neurons in the hidden layer: 4–6.
- Error function: sum of squares.
- Output function: linear.

The operation of the MPL network consists of: input data, determining the output values of hidden neurons, and determining the output value of the output neuron. The result of the network depends on: the value of the weights of hidden and output neurons and the structure of the network. Learning of unidirectional networks is performed by a “teacher”. This means that the values entered as inputs to the network together with the corresponding output values enter the learning set. The aim of the learning process is, therefore, to generate such values that determine the weights for which the network outputs will coincide with the real values. The learning process is expected to result in a reduction of the network error, which is an aggregated measure of the difference between the actual output values (test results) and the calculated ones (generated during prediction). A bidirectional information flow can be identified in the network. Namely: from the input layer to the output layer. The information necessary to calculate the output variables is transported and from the output layer to the input layer. The error information used during the learning process is transmitted. Due to the orientation of the error information flow, the algorithm is called backward error propagation. Note the number of data analysed (50 results for each moisture content). A total of 150 results were obtained, which are summarised accordingly (Table 3). Figure 11 shows a view of the input and output vector selection window.



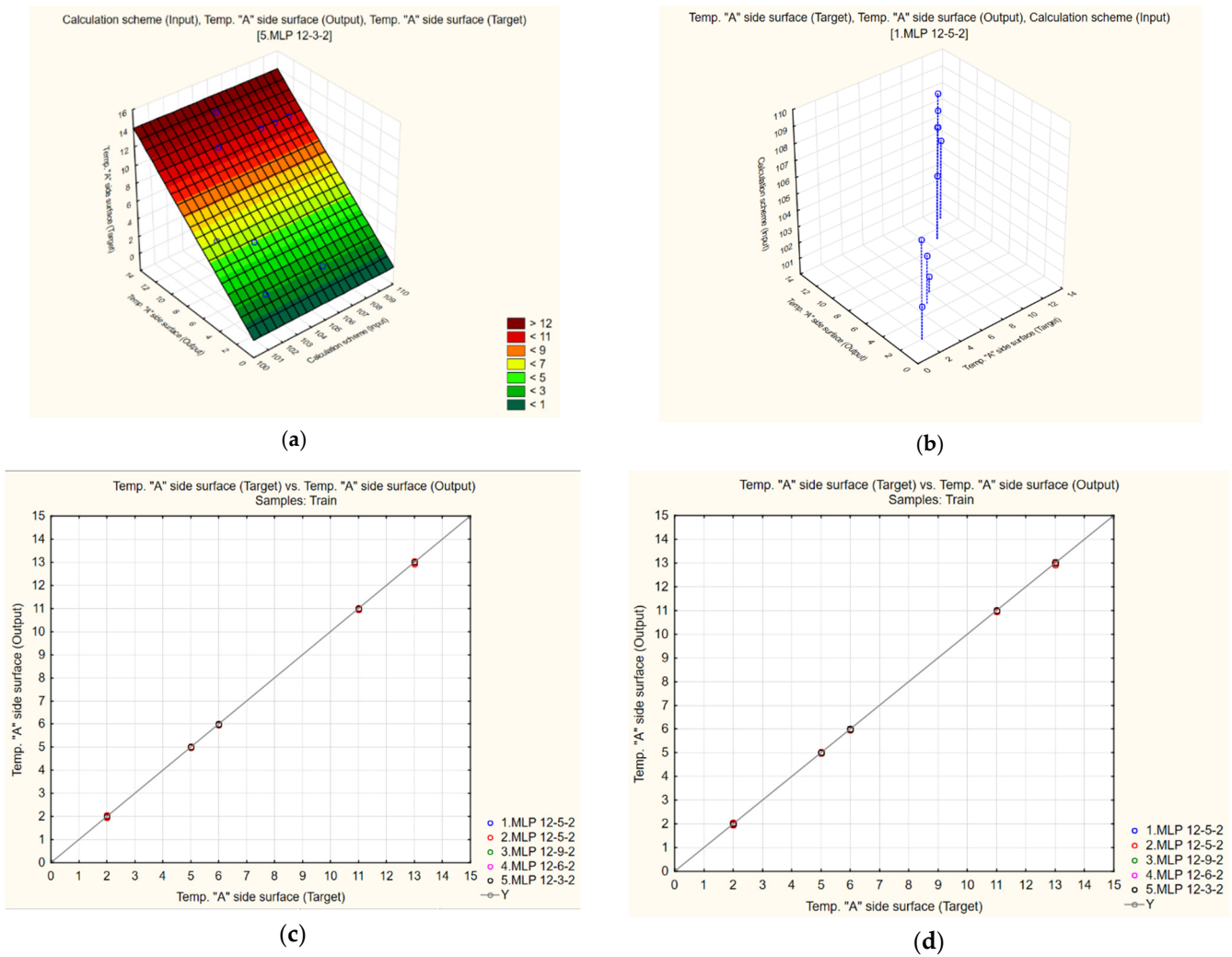
**Figure 11.** Selection of the input and output vector.

In solving regression problems, the explanatory variable (temperature at the partition surface) is quantitative. While the output explanatory variables can be quantitative (temperature, humidity) or/and qualitative (calculation scheme). The results were analysed according to the defined network topology. The results obtained as a result of the network operation explain the problem with high precision, as the validation (quality of forecasting is understood as the comparison of the forecasted value with the values from the validation set (Table 5), i.e., the one on which the program did not learn or test) amounted to 98%, which should be considered a correct result at this level of neural network creation. Example results of temperature value prediction (for a single network and ensemble of networks) are presented in Table 4 and graphically in Figure 12.

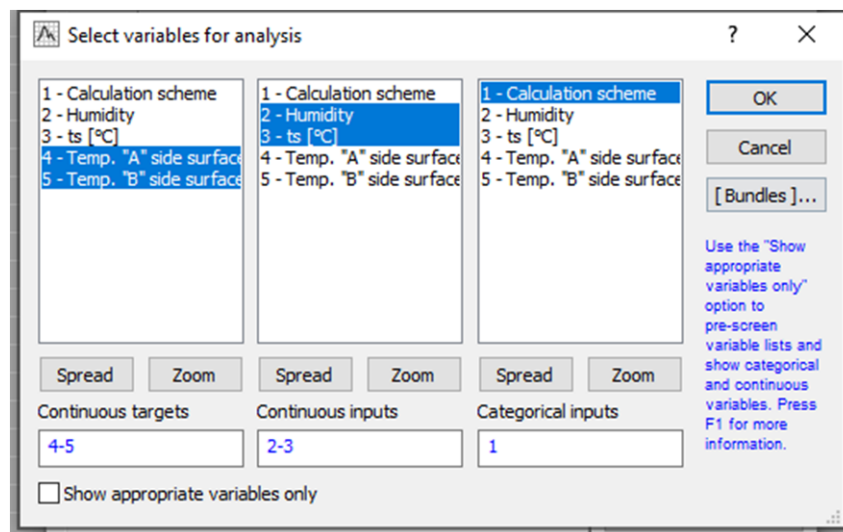
The graph presented in Figures 12 and 13 shows the fitting of the network results. The abscissa axis shows the output variable, i.e., the temperatures obtained from the tests, while the ordinate shows the values obtained as a result of the programme's prediction. Analysing the above results, it is possible to notice a good fit of the network to the analysed problem, as the graph does not show the occurrence of significant network errors.

**Table 5.** Sensitivity analysis.

Networks	Calculation Scheme	$t_s$	Humidity
MLP 12-5-2	2.91	24.54	24.04
MLP 12-5-2	5.37	8.13	7.26
MLP 12-9-2	6.51	1.00	1.00
MLP 12-6-2	1.06	1.01	1.02
MLP 12-3-2	2.77	30.56	31.24



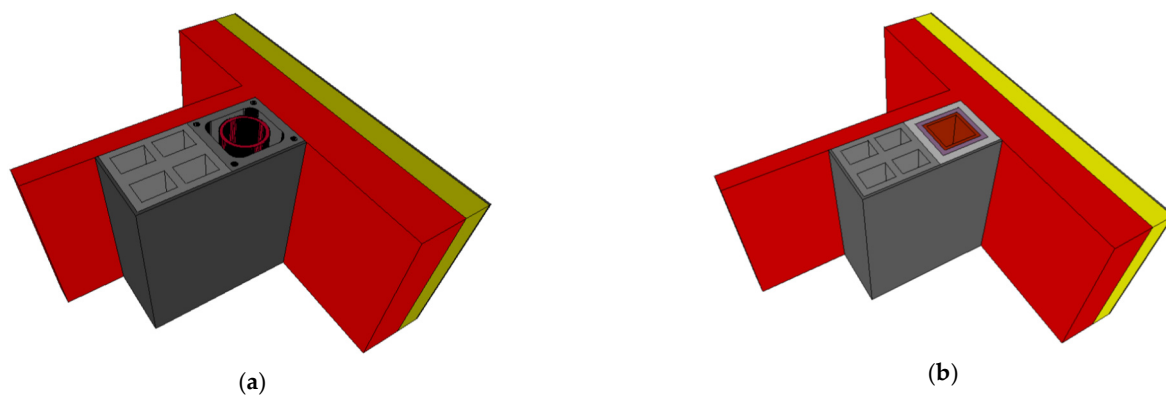
**Figure 12.** Graphical presentation of the network results (a) scheme of temp. A according to predicted value, (b) scheme of temp. A according to predicted value and calculation scheme, (c,d) scheme of temp. A according to predicted value for five different spreadsheets.



**Figure 13.** Matching the results of network runs to set input variables.

#### 4. Discussion

The article deals with facilities that have been in operation for many years, as well as newer ones that are equipped with obsolete technological solutions, not only in terms of environmental protection but also for the users themselves. The trend towards maximum energy efficiency, which is already unstoppable today, should take into account this traditional substance that is holding it back. It is not popular nowadays to mention such buildings that shatter the statistics indicating steadily decreasing CO<sub>2</sub> emissions into the atmosphere by striving for energy-efficient buildings, zero-energy buildings, and passive buildings. In the presented analyses, the authors propose solutions that significantly improve the situation of indoor air exchange and are technically and financially feasible to implement in widely understood traditional construction. The results confirm the trend of recent years presented in the literature review. In the near future, the authors intend to address the model shown in Figure 14 of a multifunctional chimney: including one smokestack and a combination of ventilation for flue gas.



**Figure 14.** Actual model of the multifunctional chimney (a), substitute of the calculated model (b).

After analysing the broader context of the issue, it will be possible to answer questions such as: what can be done with technologically older and historic buildings, especially those under conservation protection? It is certainly necessary here to think about working out concrete and feasible solutions for them, which will also allow them to be on the path of technological and energy-saving progress, but without detriment to themselves. We cannot turn a blind eye and pretend that these problems do not exist. An important role of ventilation systems, including traditional ones, is the exchange of an appropriate amount of used and humid air in rooms, which should be ensured to maintain the expected microclimate in rooms, as well as to properly maintain the building envelope, and at the same time extend its lifespan.

Furthermore, the conditions that are not strongly influenced by the user in everyday life, such as building physics, heating systems, or fuel prices in the world, there is also conscious energy management. The basic problem, however, is the efficiency knowledge of the users in the field of energy-saving, even when there are no tangible benefits, e.g., monetary (when there is no possibility of individual cost accounting). Unfortunately, in buildings where the heating system is not efficient, and there is no possibility of regulation, rational heat management is very difficult.

It should be stressed that measurable effects in reducing air pollutant emissions will be brought by both the use of high-quality coal (high calorific value and low sulphur content) and the promotion of combustion of qualified coal fuels (high calorific value and low sulphur content with repeatable quality parameters) in highly efficient boilers. Replacement of high emission boilers with modern boilers (fired by gas or biofuels) or integrated heating systems based on solid fuel burning stoves combined with the use of renewable energy sources (e.g., heat pumps, solar collectors) will also contribute to reducing emissions and improving energy utilisation.

Above all, in poorly insulated buildings with old, worn-out, and low-efficiency heating systems, despite very high heat consumption, rooms can remain underheated. The most vulnerable rooms are those located at the ends of the installation. This situation not only generates high energy consumption and air pollutant emissions but also results in high costs associated with the use of energy carriers. According to all forecasts and trends in recent years, energy carriers will become more expensive in practically every form. This is due to several factors. First and foremost, the ever-increasing global demand for energy. Another major factor is the increasing dependence on supplies of energy carriers from politically unstable countries. In addition, the progressive increase in the costs of energy production and extraction (the need to search for deposits of natural resources that are increasingly difficult to access) and climate threats cause the introduction of increasing restrictions on the domestic production of pollution.

It can be seen, for example, that the use of a low-efficiency boiler results in at least a 30% loss of fuel. This is a typical value for boilers fired with solid fuel that are about 20 years old. For modern boilers, on the other hand, this loss is between 10% and 20%. All this translates, of course, into a reduction in the amount of fuel used and therefore in operating costs, but also in the amount of flue gases emitted into the air.

Another risk of poorly insulated building envelopes is the freezing of walls during frosty spells, which causes moisture from the air to condense on cold wall surfaces indoors, creating favourable conditions for mould and fungi to grow. Appearing dampness not only contributes to the deterioration of aesthetic conditions (stains, discolouration of paint coats, chipping, and falling of plaster), it is also the cause of a microclimate that negatively affects the health conditions of people staying in such rooms. Moreover, an increase in the humidity of partitions increases the heat transfer coefficient, and when the humidity turns into ice at a negative temperature, the thermal insulating power of the materials decreases further. Another example of poorly functioning heating systems can be the overheating of parts of rooms. A frequent cause in the situation of large cubature objects, such as schools and hospitals, are situations in the absence of the possibility of regulating the amount of heat supplied to various parts of the building. Part of the room is underheated despite the fact that the system operates at maximum efficiency. Then another part of the room is strongly overheated, and the only way to cope with the problem is to ventilate the room with cold external air.

To conclude on the role and place of traditional chimney system solutions in environmental progress and the reduction of energy consumption, it is necessary to state that only the appropriate insulation of these structures and conscious energy management can lead to real cost savings and climate protection.

**Author Contributions:** Conceptualization, D.B., A.G. and Ł.B.; methodology, D.B., A.G. and Ł.B.; software, D.B., A.G. and Ł.B.; validation, D.B., A.G., and Ł.B.; formal analysis, D.B., A.G. and Ł.B.; investigation, D.B., A.G. and Ł.B.; resources, D.B., A.G. and Ł.B.; data curation, D.B., A.G. and Ł.B.; writing—original draft preparation, D.B., A.G. and Ł.B.; writing—review and editing, D.B., A.G. and Ł.B.; visualization, D.B., A.G. and Ł.B.; supervision, D.B., A.G. and Ł.B.; project administration, D.B., A.G. and Ł.B.; funding acquisition, D.B., A.G. and Ł.B. All authors have read and agreed to the published version of the manuscript.

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Appendix A

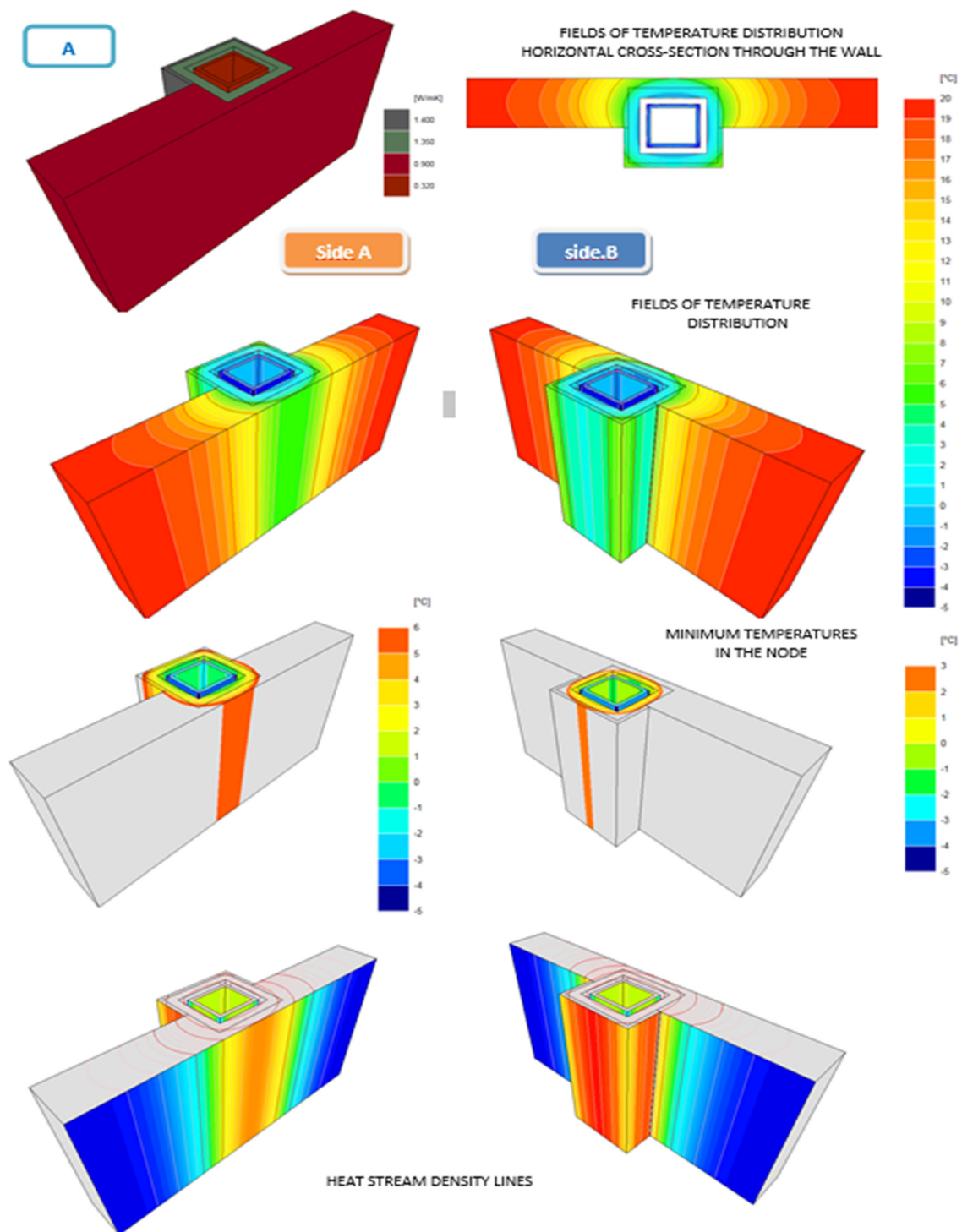


Figure A1. Scheme A: isotherm field distribution, minimum surface temperature, and heat flux distribution.

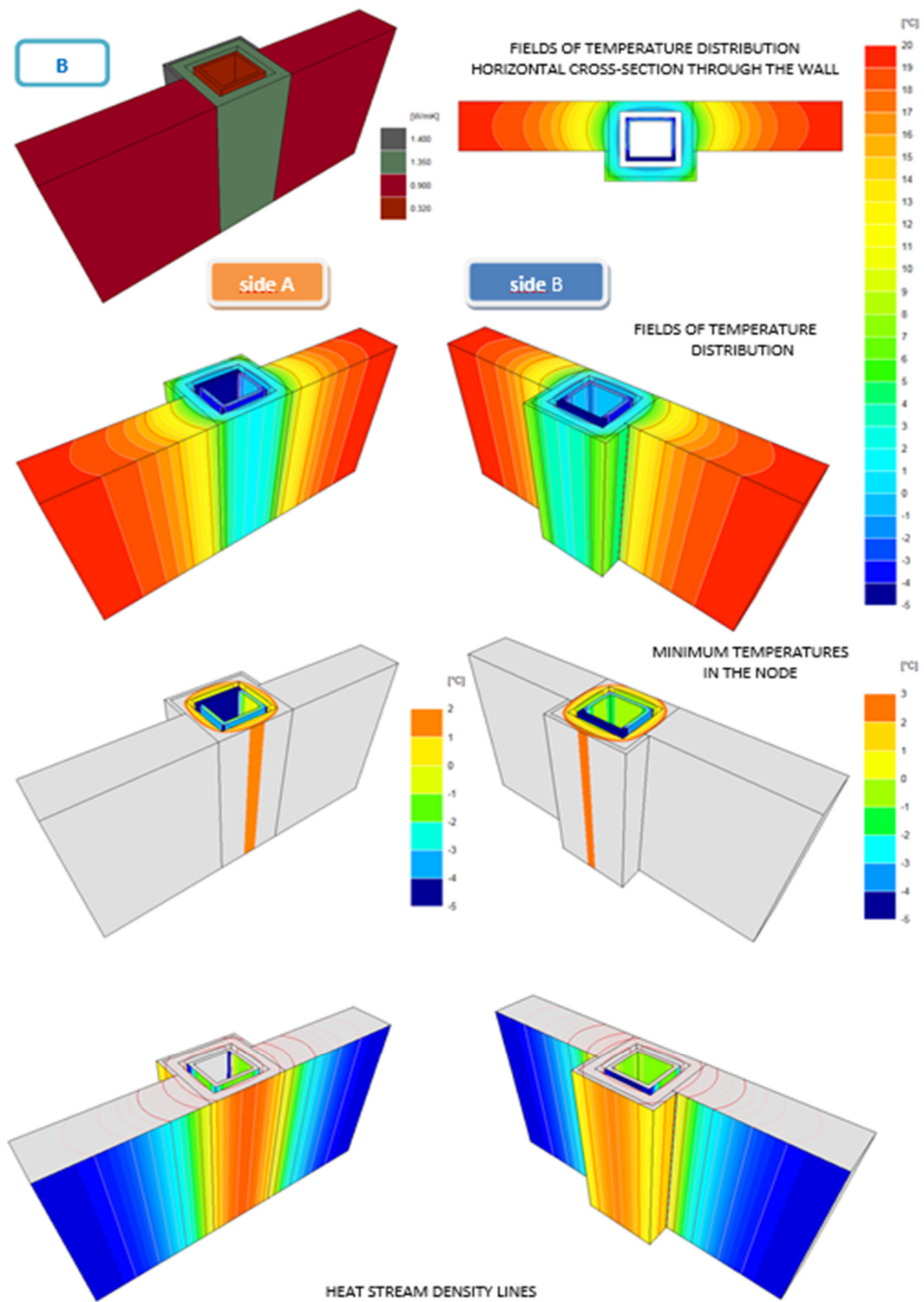


Figure A2. Scheme B: isotherm field distribution, minimum surface temperature, and heat flux distribution.

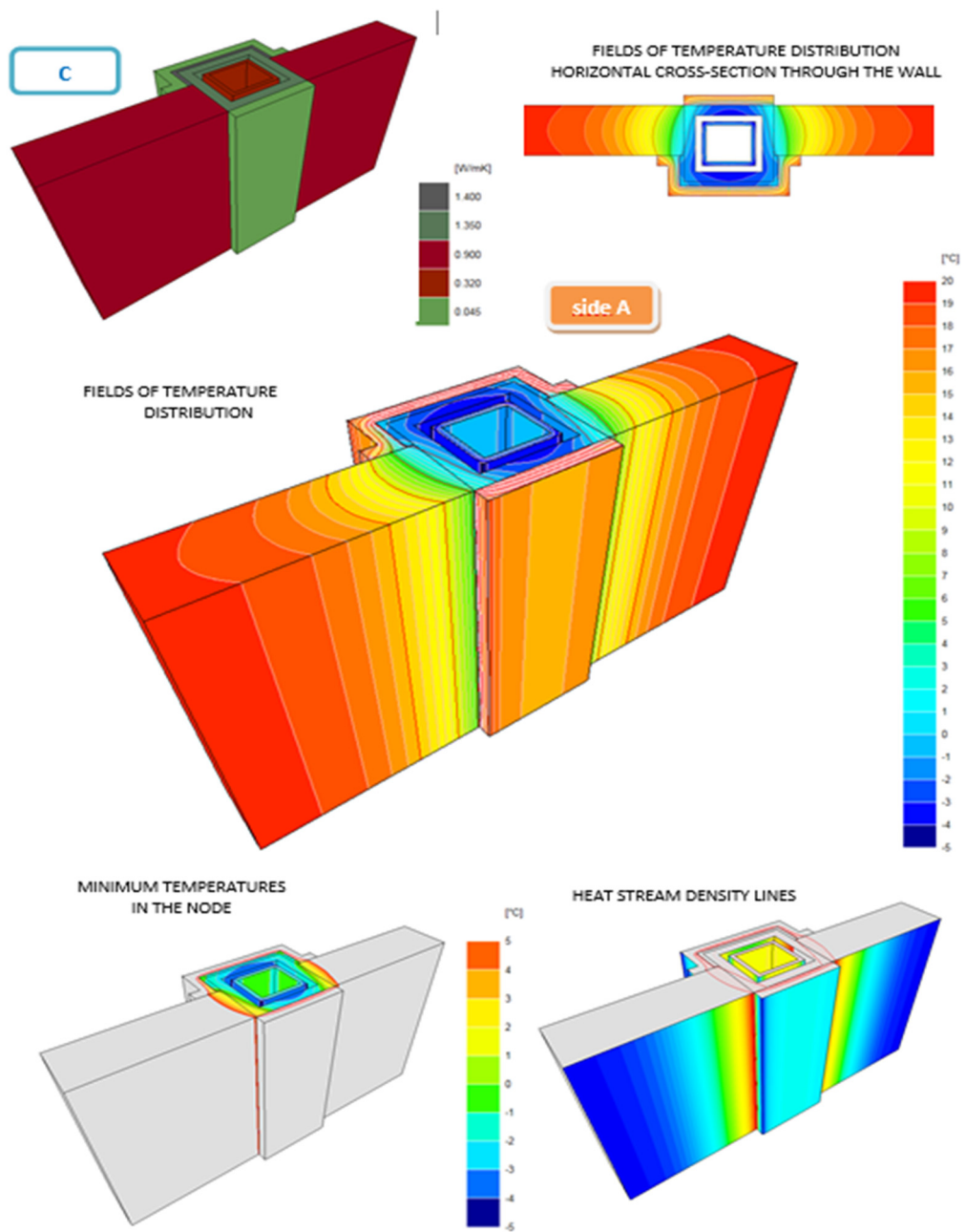


Figure A3. Scheme C: isotherm field distribution, minimum surface temperature, and heat flux distribution.

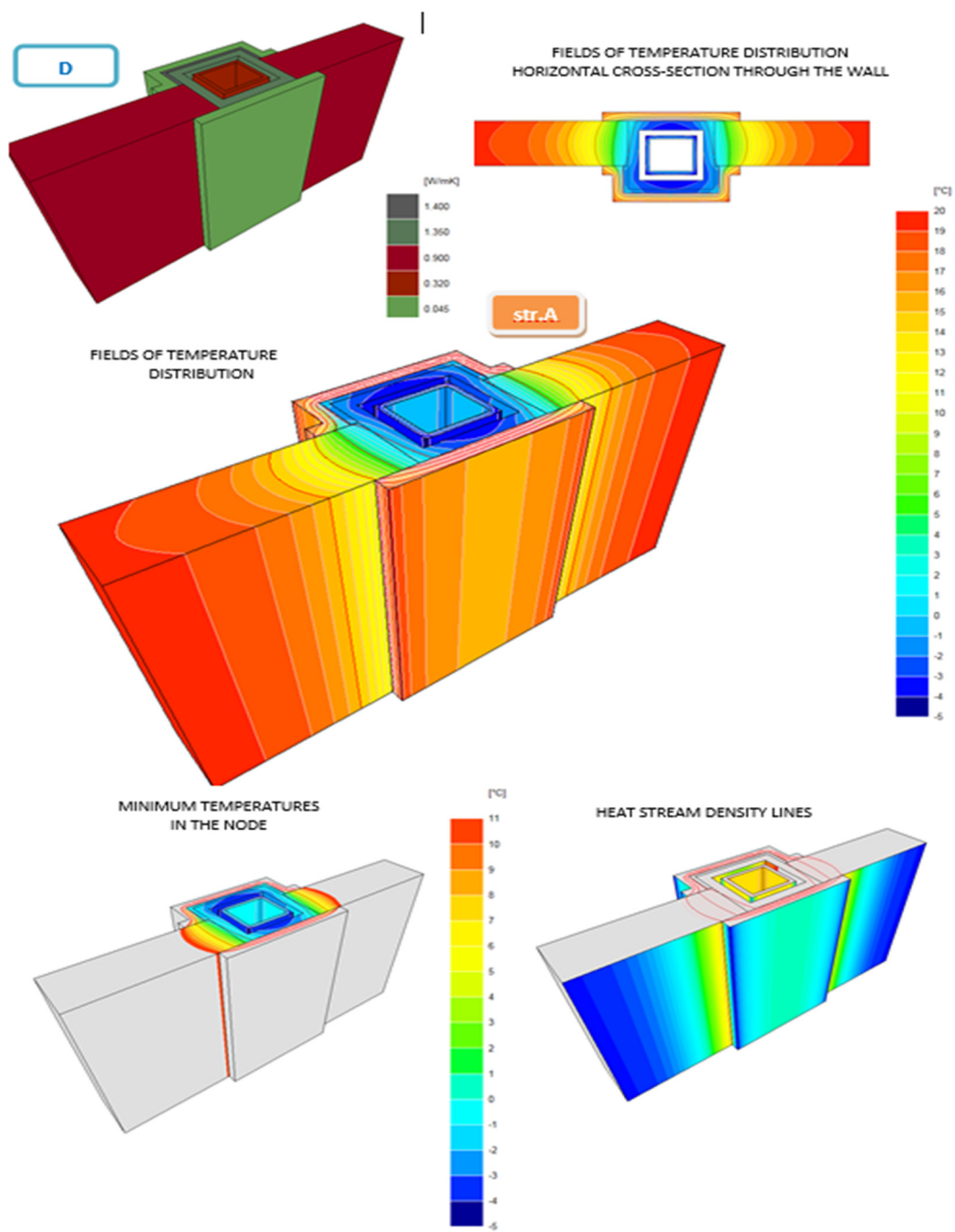


Figure A4. Scheme D: isotherm field distribution, minimum surface temperature, and heat flux distribution.

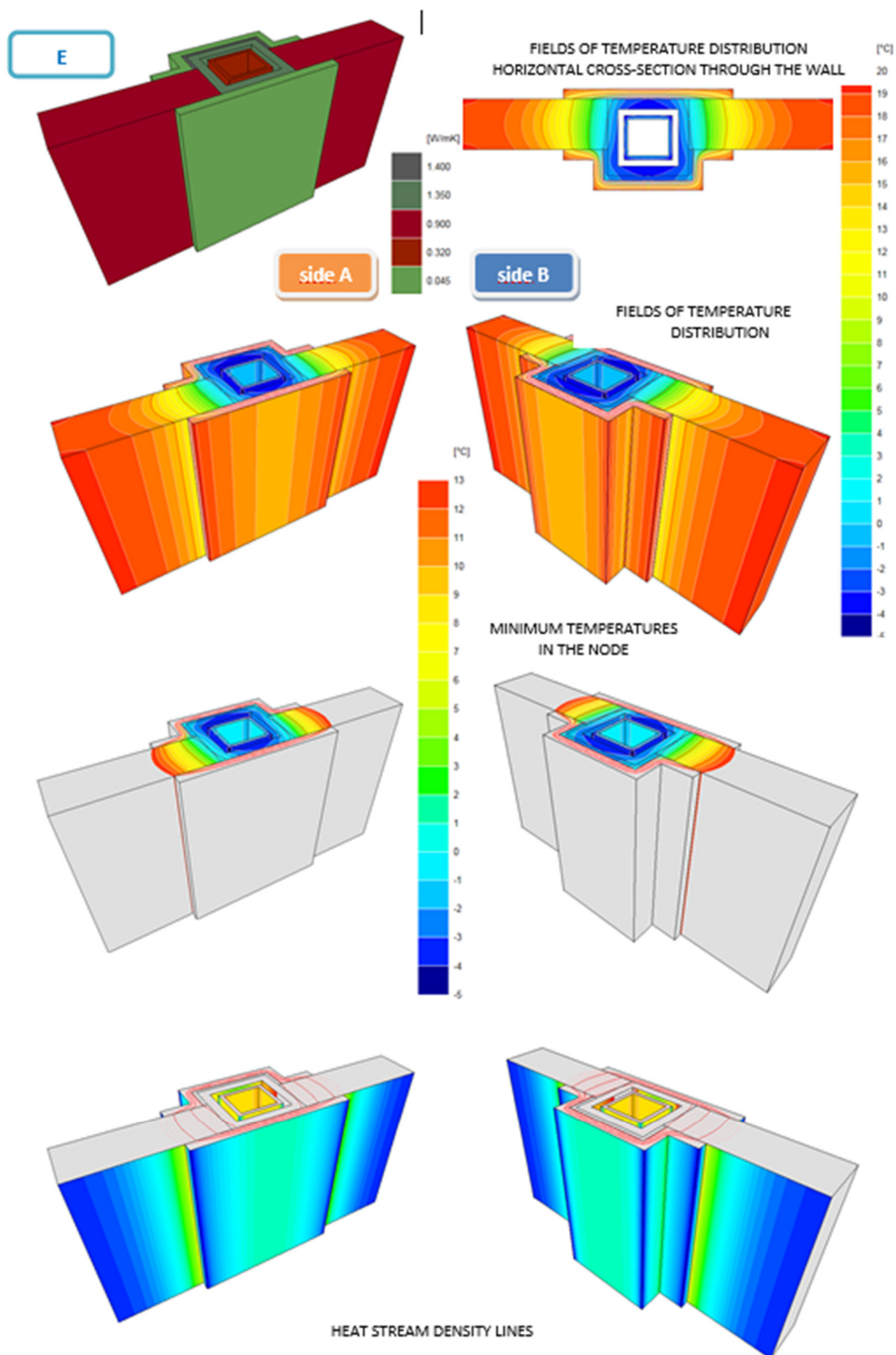


Figure A5. Scheme E: distribution of isotherms, minimum surface temperature, and heat flux distribution.



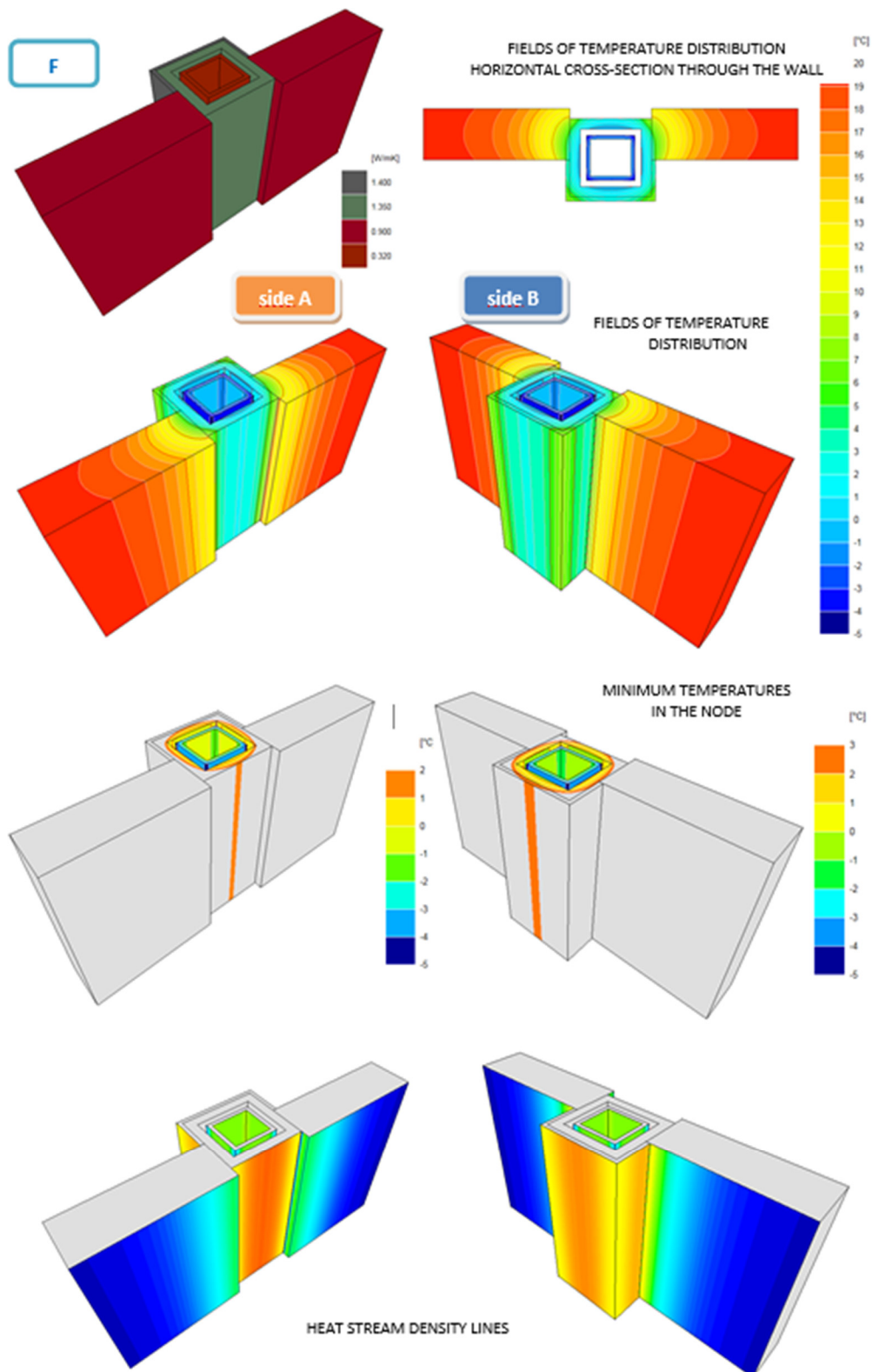


Figure A6. Scheme F: distribution of isotherm field, minimum surface temperature, and heat flux distribution.

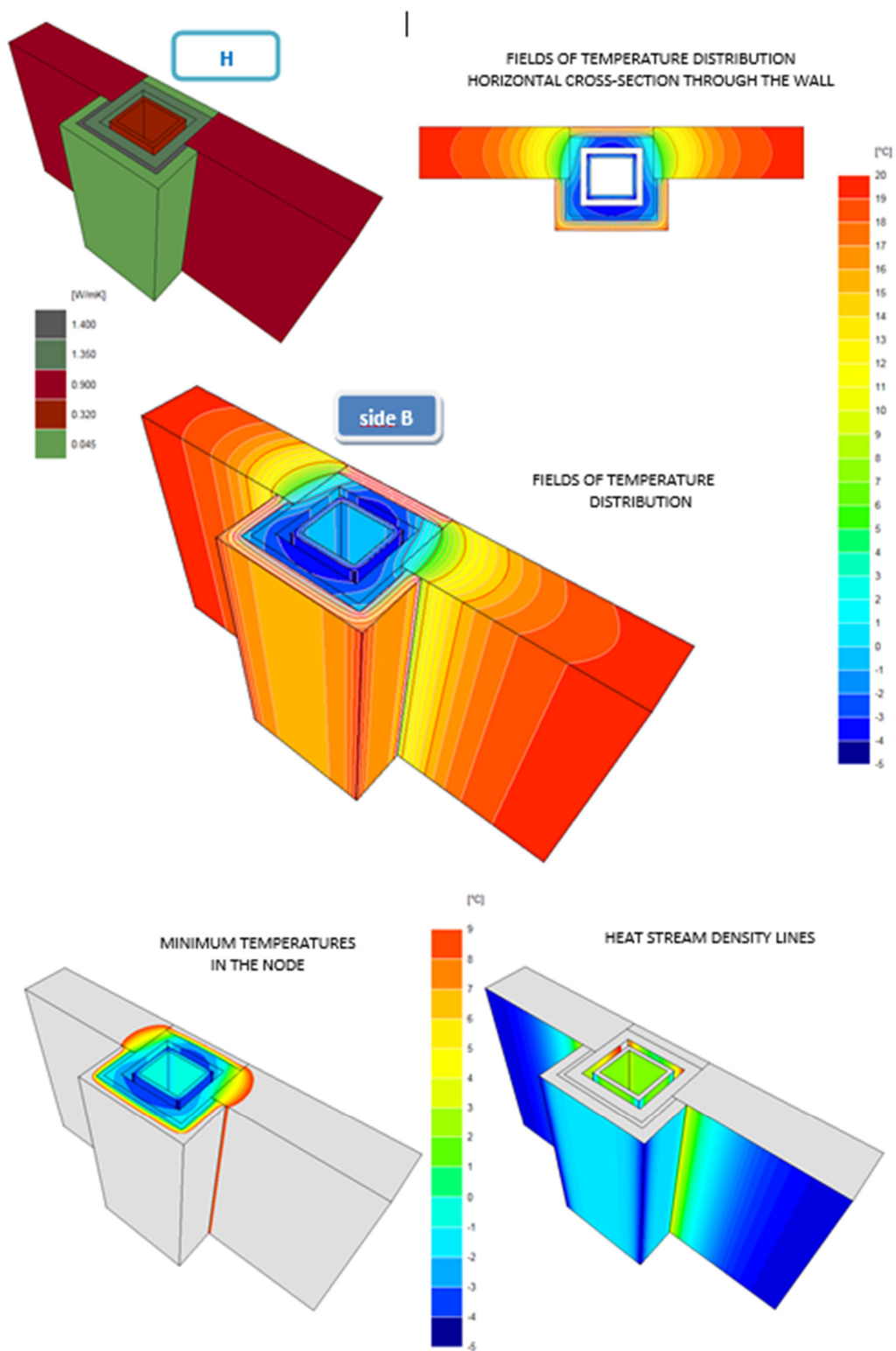


Figure A7. Scheme H: distribution of isotherm field, minimum surface temperature, and heat flux distribution.

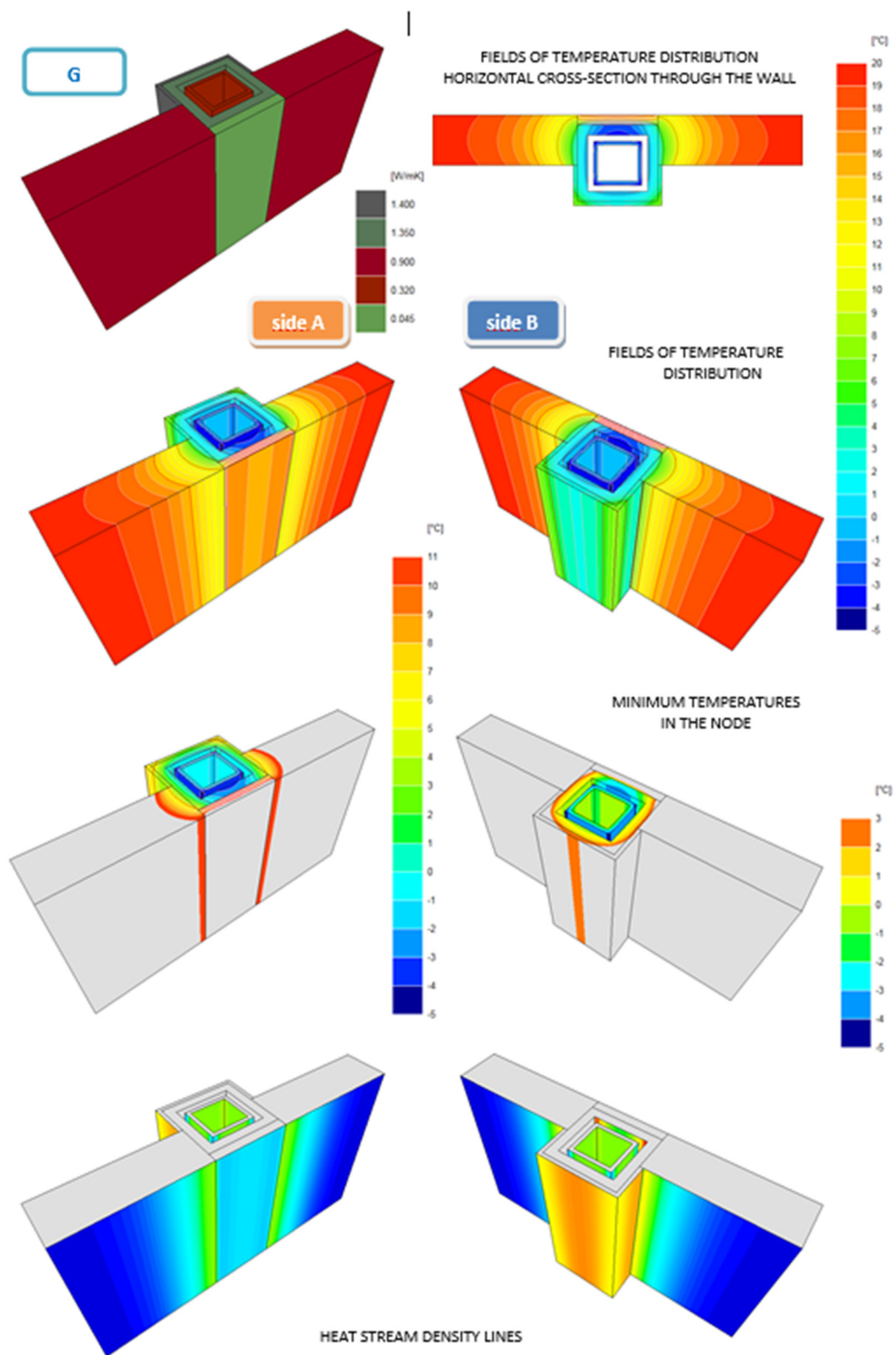


Figure A8. Scheme G: distribution of isothermal field, minimum surface temperature, and heat flux distribution.

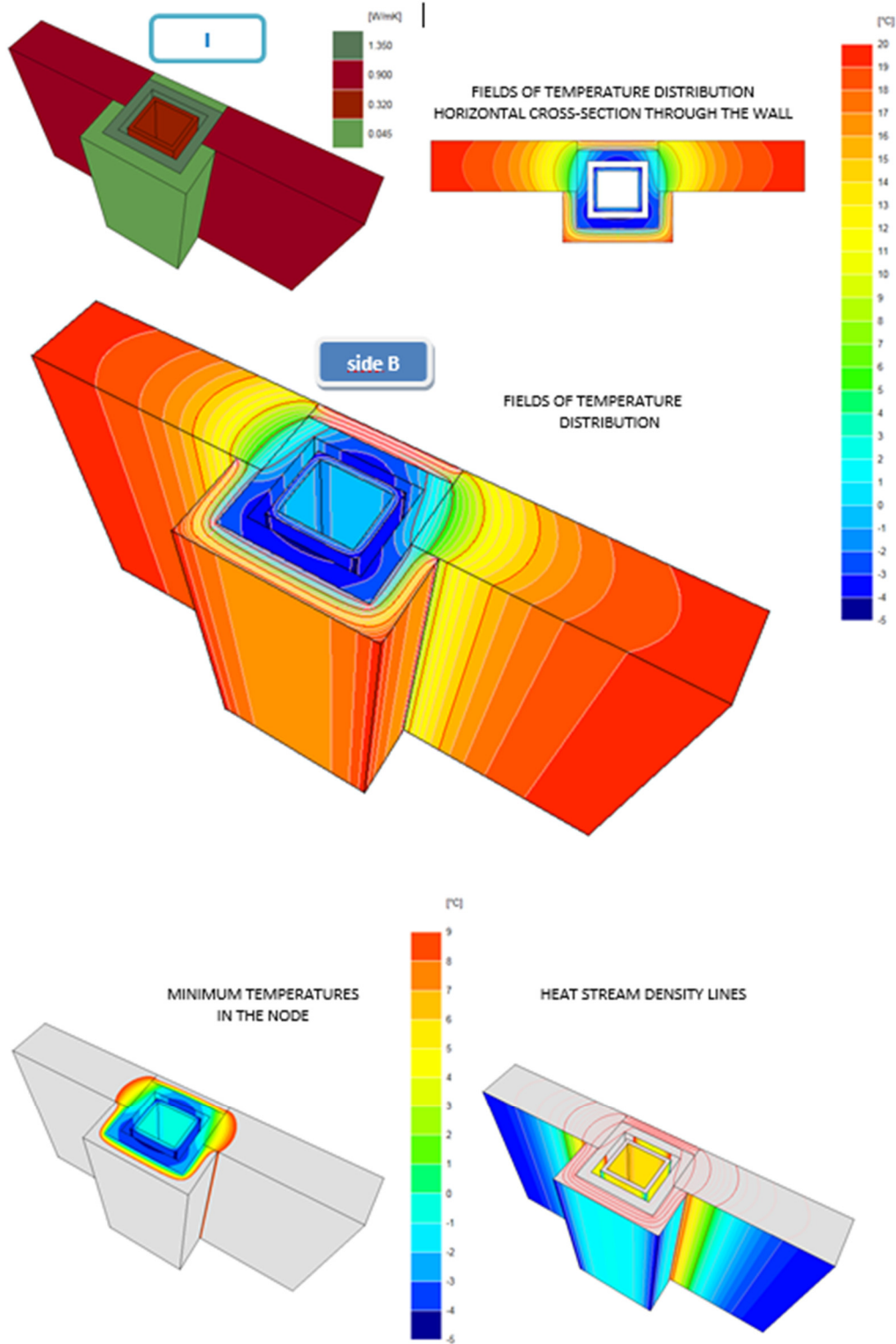


Figure A9. Scheme I: isotherm field distribution, minimum surface temperature, and heat flux distribution.

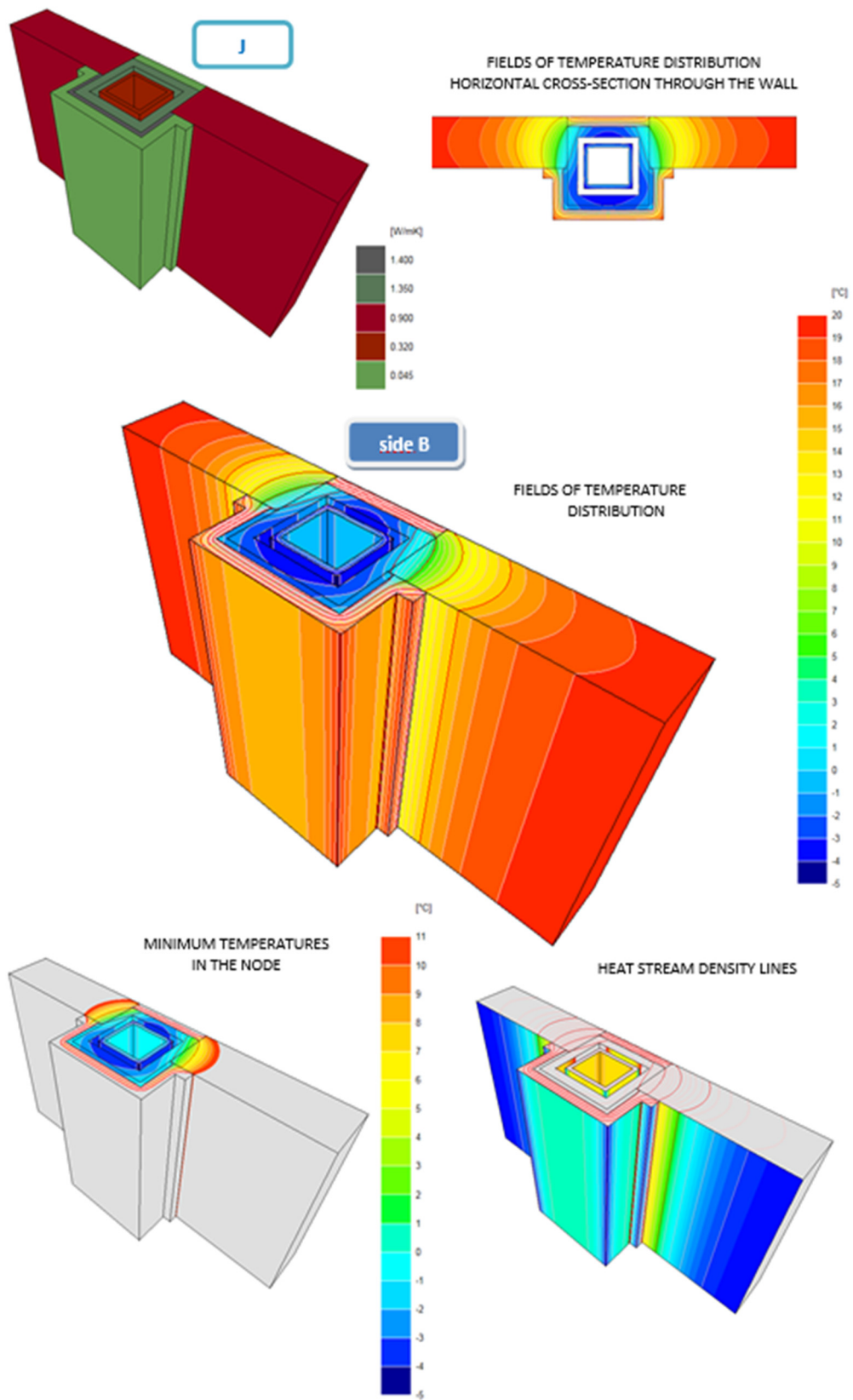


Figure A10. Scheme J: isotherm field distribution, minimum surface temperature, and heat flux distribution.



## References

1. Nowak, R. Efektywność energetyczna w aspekcie innowacyjnych systemów kominowych. *GAZ WODA Tech. Sanit.* **2020**, *1*, 20–23. [CrossRef]
2. Salata, F.; Alippi, C.; Tarsitano, A.; Golasi, I.; Coppi, M. A First Approach to Natural Thermoventilation of Residential Buildings through Ventilation Chimneys Supplied by Solar Ponds. *Sustainability* **2015**, *7*, 9649–9663. [CrossRef]
3. Motyl, P.; Wikło, M.; Bukalska, J.; Piechnik, B.; Kalbarczyk, R. A New Design for Wood Stoves Based on Numerical Analysis and Experimental Research. *Energies* **2020**, *13*, 1028. [CrossRef]
4. Rezaei, A.; Samadzadegan, B.; Rasoulia, H.; Ranjbar, S.; Abolhassani, S.S.; Sanei, A.; Eicker, U. A New Modeling Approach for Low-Carbon District Energy System Planning. *Energies* **2021**, *14*, 1383. [CrossRef]
5. Lipnicki, Z.; Gortych, M.; Staszczuk, A.; Kuczyński, T.; Grabas, P. Analytical and Experimental Investigation of the Solar Chimney System. *Energies* **2019**, *12*, 2060. [CrossRef]
6. Hidaka, K.; Miyazawa, A.; Hu, H.; Mitsuji, K.; Nagai, Y.; Yoshimoto, N.; Suenaga, Y. Basic Study of Ventilation Using Semi-Transparent Organic Photovoltaic Sheets for Solar Chimney Systems. *Technologies* **2018**, *6*, 93. [CrossRef]
7. Han, C.; Li, G.; Ding, Y.; Yan, F.; Bai, L. Chimney Detection Based on Faster R-CNN and Spatial Analysis Methods in High Resolution Remote Sensing Images. *Sensors* **2020**, *20*, 4353. [CrossRef] [PubMed]
8. Daliga, K.; Kurałowicz, Z. Comparison of Different Measurement Techniques as Methodology for Surveying and Monitoring Stainless Steel Chimneys. *Geosciences* **2019**, *9*, 429. [CrossRef]
9. Manfren, M.; Sibilla, M.; Tronchin, L. Energy Modelling and Analytics in the Built Environment—A Review of Their Role for Energy Transitions in the Construction Sector. *Energies* **2021**, *14*, 679. [CrossRef]
10. Bonoli, A.; Zanni, S.; Serrano-Bernardo, F. Sustainability in Building and Construction within the Framework of Circular Cities and European New Green Deal. The Contribution of Concrete Recycling. *Sustainability* **2021**, *13*, 2139. [CrossRef]
11. Rutkowska, G.; Klepak, O. Problemy strat ciepła w istniejących budynkach jednorodzinnych w kontekście błędów wykonawczych. *Rocz. Ochr. Sr.* **2013**, *15*, 2625–2639.
12. Lee, K.H.; Strand, R.K. Enhancement of natural ventilation in buildings using a thermal chimney. *Energy Build.* **2009**, *41*, 615–621. [CrossRef]
13. Adamu, Z.A.; Price, A.D. Natural Ventilation with Heat Recovery: A Biomimetic Concept. *Buildings* **2015**, *5*, 405–423. [CrossRef]
14. Kim, J.; Kim, Y. Optimal Combination of External Wall Insulation Thickness and Surface Solar Reflectivity of Non-Residential Buildings in the Korean Peninsula. *Sustainability* **2021**, *13*, 3205. [CrossRef]
15. Zhang, D.; Yang, Y.; Pan, M.; Gao, Z. Toward a Heat Recovery Chimney. *Sustainability* **2011**, *3*, 2115–2128. [CrossRef]
16. PN-EN 1443:2019-05 Chimneys-General Requirements. Available online: <https://sklep.pkn.pl/pn-en-1443-2019-05e.html> (accessed on 30 July 2021).
17. Rahman, M.M.; Chu, C.-M. *Cold Inflow-Free Solar Chimney*; Rahman, M.M., Chu, C.-M., Eds.; Springer: Singapore, 2021; ISBN 978-981-33-6830-9.
18. Soto, A.; Martínez, P.J.; Tudela, J.A. Simulation and experimental study of residential building with north side wind tower assisted by solar chimneys. *J. Build. Eng.* **2021**, *43*, 102562. [CrossRef]
19. Drozdol, K. CFD Thermal Analysis of a Three-layer Chimney Used in Residential Buildings. *J. Build. Eng.* **2021**, *44*, 102665. [CrossRef]
20. Kurpińska, M.; Karwacki, J.; Maurin, A.; Kin, M. Measurements of Thermal Conductivity of LWC Cement Composites Using Simplified Laboratory Scale Method. *Materials* **2021**, *14*, 1351. [CrossRef]
21. Antczak-Jarząbska, R.; Niedostatkiewicz, M. Wpływ nasady kominowej na poprawę sprawności użytkowej wentylacji grawitacyjnej. *Przegląd Bud.* **2017**, *88*, 48–52.
22. Pawłowski, K.; Nakielska, N. Selected design aspects of sections and joints in low energy buildings. *Bud. Zoptymalizowanym Potencjale Energ.* **2018**, *7*, 123–132. [CrossRef]
23. Saifi, N.; Settou, N.; Dokkar, B.; Negrou, B.; Chennouf, N. Experimental Study And Simulation Of Airflow In Solar Chimneys. *Energy Procedia* **2012**, *18*, 1289–1298. [CrossRef]
24. Leppänen, P.; Inha, T.; Pentti, M. An Experimental Study on the Effect of Design Flue Gas Temperature on the Fire Safety of Chimneys. *Fire Technol.* **2014**, *51*, 847–866. [CrossRef]
25. Pallarés, F.J.; Ivorra, S.; Pallarés, L.; Adam, J.M. State of the art of industrial masonry chimneys: A review from construction to strengthening. *Constr. Build. Mater.* **2011**, *25*, 4351–4361. [CrossRef]
26. Straatman, A.G.; Tarasuk, J.D.; Floryan, J.M. Heat Transfer Enhancement from a Vertical, Isothermal Channel Generated by the Chimney Effect. *J. Heat Transf.* **1993**, *115*, 395–402. [CrossRef]
27. Jörg, O.; Scorer, R. An experimental study of cold inflow into chimneys. *Atmospheric Environ.* **1967**, *1*, 645–654. [CrossRef]
28. McCloskey, F.G.; The Northern Ireland Housing Executive. Failures in traditionally constructed domestic chimneys. In Proceedings of the 8th International Brick/Block Masonry Conference, Dublin, Ireland, 19–21 September 1988; pp. 1732–1738.
29. Zhang, H.; Yang, D.; Tam, V.W.; Tao, Y.; Zhang, G.; Setunge, S.; Shi, L. A critical review of combined natural ventilation techniques in sustainable buildings. *Renew. Sustain. Energy Rev.* **2021**, *141*, 110795. [CrossRef]
30. Corradi, M.; Di Schino, A.; Borri, A.; Rufini, R. A review of the use of stainless steel for masonry repair and reinforcement. *Constr. Build. Mater.* **2018**, *181*, 335–346. [CrossRef]

31. Hartinger, S.M.; Commodore, A.A.; Hattendorf, J.; Lanata, C.F.; Gil, A.I.; Verastegui, H.; Aguilar-Villalobos, M.; Mäusezahl, D.; Naeher, L.P. Chimney stoves modestly improved Indoor Air Quality measurements compared with traditional open fire stoves: Results from a small-scale intervention study in rural Peru. *Indoor Air* **2013**, *23*, 342–352. [CrossRef]
32. Maj, M.; Ubysz, A.; Hammadeh, H.; Askifi, F. Non-Destructive Testing of Technical Conditions of RC Industrial Tall Chimneys Subjected to High Temperature. *Materials* **2019**, *12*, 2027. [CrossRef]
33. Al-Absi, Z.; Hafizal, M.; Ismail, M.; Ghazali, A. Towards Sustainable Development: Building's Retrofitting with PCMs to Enhance the Indoor Thermal Comfort in Tropical Climate, Malaysia. *Sustainability* **2021**, *13*, 3614. [CrossRef]
34. Leng, P.; Ling, G.H.T.; Ahmad, M.; Ossen, D.; Aminudin, E.; Chan, W.; Tawasil, D. Thermal Performance of Single-Story Air-Welled Terraced House in Malaysia: A Field Measurement Approach. *Sustainability* **2020**, *13*, 201. [CrossRef]
35. Ustawa z 10 Września 2015 r. o Zmianie Ustawy–Prawo Ochrony Środowiska. Dziennik Ustaw RP z 12 Października 2015 r. poz. 1593. Available online: <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20150001593> (accessed on 30 July 2021).
36. Ustawa z Dnia 7 Lipca 1994 r. Prawo Budowlane (Dz. U. z 2018 r. poz. 1202. 1276. 1496 i 1669). Available online: <http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180001202> (accessed on 30 July 2021).
37. Rozporządzenie Ministra Infrastruktury z Dnia 12 Kwietnia 2002 r. w Sprawie Warunków Technicznych. Jakim Powinny Odpowiadać Budynki i Ich Usytuowanie (Tekst Jednolity Dz. U. z 2017 r. poz. 1523). Available online: <https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20020750690> (accessed on 30 July 2021).
38. Rozporządzenie Ministra Transportu. Budownictwa i Gospodarki Morskiej z Dnia 5 Lipca 2013 r. Zmieniające rozporządzenie w sprawie warunków technicznych. Jakim powinny Odpowiadać Budynki i Ich Usytuowanie (Dz. U. Poz. 926). Available online: <http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20130000926> (accessed on 30 July 2021).
39. Rozporządzenie Parlamentu Europejskiego i Rady (UE) nr 305/2011 z Dnia 9 Marca 2011 r. Ustanawiające Zharmonizowane Warunki Wprowadzania do Obrotu Wytworów Budowlanych i Uchylające Dyrektywę Rady 89/106/EEG. Available online: <https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:02011R0305-20140616&qid=1576663491684&from=EN> (accessed on 30 July 2021).
40. Dyrektywa Parlamentu Europejskiego i Rady 2010/30/UE z Dnia 19 Maja 2010 r. w Sprawie Wskazania Poprzez Etykietowanie Oraz Standardowe Informacje o Produkcie. Zużycia Energii Oraz Innych Zasobów Przez Produkty Związane z Energią. Available online: <https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=OJ:L:2010:153:FULL&from=NL> (accessed on 30 July 2021).
41. Dyrektywa 5 Parlamentu Europejskiego i Rady 2005/32/WE z Dnia 6 Lipca 2005. Available online: <https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32005L0032&from=en> (accessed on 30 July 2021).
42. Ustawa z Dnia 29 Sierpnia 2014 r. o Charakterystyce Energetycznej Budynków (Dz. U. poz. 1200 oraz z 2015 r. poz. 151). Available online: <http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20140001200> (accessed on 30 July 2021).
43. Dyrektywa Parlamentu Europejskiego i Rady 2009/125/WE z dnia 21 Października 2009 r. Ustanawiająca Ogólne Zasady Ustalania Wymogów Dotyczących Ekoprojektu dla Produktów Związanych z Energią. Available online: <https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32009L0125&from=ES> (accessed on 30 July 2021).
44. Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Using Products and Amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council. Available online: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0058:EN:PDF> (accessed on 30 July 2021).
45. *Green Paper—A European Strategy for Sustainable, Competitive and Secure Energy*; Official Journal of the European Union: Brussels, Belgium, 2006.
46. Bajno, D. Ventilation as a particular safety element in housing development. In *Monografia Rudolf Kania Opole*; Polish Engineering Association (NOT): Vienna, Austria, 2011; pp. 173–180.
47. PN-EN 1859+A1:2013-09 Kominy-Metody Badań. Available online: <https://sklep.pkn.pl/pn-en-1859-a1-2013-09p.html> (accessed on 30 July 2021).
48. Qiao, M.; Xu, F.; Saha, S.C. Scaling analysis and numerical simulation of natural convection from a duct. *Numer. Heat Transfer. Part A Appl.* **2017**, *72*, 355–371. [CrossRef]
49. Fedorczyk-Cisak, M. Efektywność energetyczna oraz niska emisja w krajowych i regionalnych uwarunkowaniach prawnych. *Mater. Bud.* **2016**, *1*, 22–24. [CrossRef]
50. Ujma, A.; Kysiak, A. Diagnostyka elementów konstrukcji budynków z wykorzystaniem kamery termowizyjnej. *Bud. Zoptymalizowanym Potencjale Energ.* **2015**, *1*, 182–190.
51. Knyziak, P. Sztuczne sieci neuronowe w oszacowaniu zużycia technicznego budynków mieszkalnych. In *Theoretical Foundation of Civil Engineering*; Oficyna Wydawnicza Politechniki Warszawskiej: Warszawa, Poland, 2008; Volume 16.
52. Osowski, S. Sztuczne sieci neuronowe-Podstawowe struktury sieciowe i algorytmy uczenia. *Prz. Elektrotechniczny* **2009**, *85*, 1–8.
53. Żurada, J.; Barski, M.; Jędruch, W. Sztuczne sieci neuronowe. *Ann* **2004**, *1*, 16–19.
54. Chithra, S.; Kumar, S.S.; Chinnaraju, K.; Ashmita, F.A. A comparative study on the compressive strength prediction models for High Performance Concrete containing nano silica and copper slag using regression analysis and Artificial Neural Networks. *Constr. Build. Mater.* **2016**, *114*, 528–535. [CrossRef]
55. Jasienko, J.; Bednarz, Ł.; Nowak, T. The effectiveness of strengthening historic brick vaults by contemporary methods. In *Proceedings of the Protection of Historical Buildings, PROHITECH 09, Rome, Italy, 21–24 June 2009*; pp. 1299–1304.

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56. Bajno, D.; Bednarz, L.; Matkowski, Z.; Raszczuk, K. Monitoring of Thermal and Moisture Processes in Various Types of External Historical Walls. *Materials* **2020**, *13*, 505. [[CrossRef](#)]
  57. Bajno, D. Defekty konstrukcyjno–budowlane w procesie realizacji oraz na etapie eksploatacji tradycyjnych kominów w budynkach mieszkalnych. In *Szkody Kominowe*; Rudolf Kania: Opole, Poland, 2015; pp. 103–120.
  58. ISO 12011-Technical Product Documentation-Technical Drawings; Lines-Part 1: Basic Conventions. Available online: <https://www.iso.org/obp/ui/#iso:std:iso:128:-1:ed-1:en> (accessed on 30 July 2021).
  59. PN-EN ISO 6946: 2008 Komponenty Budowlane i Elementy Budynku. Opór Ciepły i Współczynnik Przenikania Ciepła. Metoda Obliczania. Available online: <http://sklep.pkn.pl/pn-en-iso-6946-2008d.html> (accessed on 30 July 2021).