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USING SOLIDWORKS SIMULATION TOOL FOR AUTOMATED DESIGN OF DRYING CHAMBERS AND STUDY OF THEIR OPERATION PARAMETERS

The paper proposes a modern approach to the automated design of three-dimensional models of wood drying chambers and the study of their operation parameters using the SolidWorks Simulation tool, which makes it possible to create various information models using computer tools. Therefore, in this paper, a three-dimensional model of a wood drying chamber was developed and presented, which includes its main components: walls, ceilings, door, stacks of lumber to be dried, a fresh air supply system, a system for its circulation through fans and heating through heaters. For the automated design of three-dimensional models of all these components, the corresponding algorithms were also developed and programmatically implemented using a specialized SolidWorks application programming interface. At the same time, the developed software application takes into account the parameters entered by the user, including the size, quantity, and type of lumber to be dried. In addition, several thermal calculations were performed across the stack, including with different air velocities. This allows us to analyze the effect of this speed on the distribution of heat transfer across the stack. In general, the obtained results are automatically displayed in one of the windows of the software application. This approach makes it possible to obtain results in the background of SolidWorks with minimal user intervention. Despite the fact that such studies are carried out in SolidWorks Simulation, the graphical results, including the temperature distribution across the stack, are fully automated without user intervention. The software application also makes it possible to automatically change the geometry of a three-dimensional model of a wood drying chamber or stacks within specified limits. In turn, the use of the developed software application in combination with SolidWorks Simulation can effectively speed up the process of creating three-dimensional models of wood drying chambers and studying their operation parameters. In general, this work reflects the trend towards digital transformation in industry, opening up new opportunities for woodworking enterprises and contributing to their market competitiveness and production efficiency.
Keywords: thermal calculation; 3D design; computer modeling; SolidWorks API; lumber; heat transfer; software.

Introduction / Вступ

In this work, a 3D model of a drying chamber is being developed and its operation parameters are being studied using SolidWorks Simulation. To control the input parameters of the drying chamber, it is necessary to develop appropriate software. At the same time, the software should display the simulation results in the background using the SolidWorks API. In addition, the main types of analysis are being performed, including thermal analysis. It involves determining the distribution of heat fluxes in the stack, which is important in terms of analyzing the wood drying process. It also involves studying the effect of different air velocities on heat distribution across the stack.

In the world scientific literature, the issue of computer-aided design of 3D models of drying chambers and the study of physical processes in them is a relevant topic in the engineering and production environment, and is of great interest to industry experts. Such researchers as Yu. M. Huber, Ya. I. Sokolovskyy, I. B. Boretska, along with many other scientists, have made a significant contribution to the development of this field and improved the existing methods of computer-aided design of 3D models of drying chambers and optimization of their design. Most of them use advanced technologies for efficient use of resources and improvement of technological processes, which is of great importance for modern industry and production.

The relevance of the study consists in the fact that the process of creating information models using computer tools is becoming increasingly important in all areas of practice, and the woodworking industry is no exception. The use of CAD/CAE systems, such as SolidWorks, is proving to be an indispensable tool for designing and analyzing thermophysical and aerodynamic processes in wood drying chambers. Such systems allow engineers and researchers to perform comprehensive modeling, covering not only geometric aspects, but also a detailed study of the physical properties of the medium. This greatly facilitates the process of developing and optimizing new technologies. This approach allows not only to create more efficient drying systems, but also significantly reduces energy and resource costs, which is an important factor in today's environmental

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awareness and restraining impact on the natural environment. Therefore, research in this area is necessary for the further development and optimization of the woodworking industry and can be of great importance for improving its competitiveness in the future.

Object of research – designing of a wood drying chamber.

Subject of research – methods and tools for creating a 3D model of a wood drying chamber and analyzing it using SolidWorks environment.

The purpose of the work – to develop and analyze a 3D model of a wood drying chamber using SolidWorks Simulation with automatic output of results using the SolidWorks API.

To achieve this *purpose*, the following main *research objectives are identified*:

1. Create a 3D model of a batch wood drying chamber.
2. Simulate the heat flows that occur in the wood drying chamber and compare the results with different velocities of air.
3. Develop a specialized software application for changing the main parameters of the 3D model of wood drying chamber, entering the input data of the simulation and automatically displaying the obtained results.

Analysis of recent research and publications. The analysis of literature sources [3, 9, 10] and the practice of designing wood drying chambers indicates that their study as design objects and their computer modeling requires further significant improvement. The existing mathematical models of heat and mass transfer fields in drying chambers are based on the equations of material and heat balances [12], which determine the variable flows of mass and heat of the coolant. Based on this approach, computer modeling of drying chambers is carried out mainly in terms of control systems [5, 14]. It should be mentioned that computer models for engineering analysis of heat and mass transfer in drying chambers are quite rare.

In the last few years, due to the intensive development of computer hardware and software, the possibilities of numerical analysis have been significantly expanded due to Computer Aided Engineering (CAE) technologies, i.e., engineering analysis technologies. Within CAE, there is such a class of programs as Computational Fluid Dynamics (CFD), which are designed for computer analysis of physical fields [4, 17]. This class includes such programs as SolidWorks, Fluent, Flowvision, etc. CFD programs have proven themselves to be well used for scientific research of heat and mass transfer fields in various industries.

Research results and their discussion / Результати дослідження та їх обговорення

Creating a 3D geometric model of a wood drying chamber. To create this 3D model, was used the SolidWorks 2019 computer-aided design environment [2]. This environment and its tools are well adapted to the construction of complex surfaces and assemblies. To build a 3D model of a wood drying chamber, first, it is necessary to select its type. In this case, it will be a drying chamber of batch action. At the same time, one of the most important elements of this, as well as any other drying chamber, are heaters (Figure 1,*a*) and fans (Figure 1,*b*).

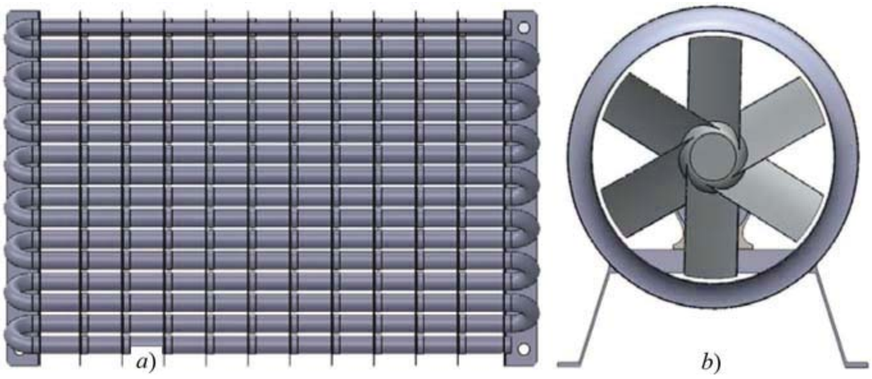

Fig. 1. View of heaters (*a*) and fans (*b*) used in the assembly of chamber / Вигляд калориферів (*а*) та вентиляторів (*b*), що використовують у збірці камери

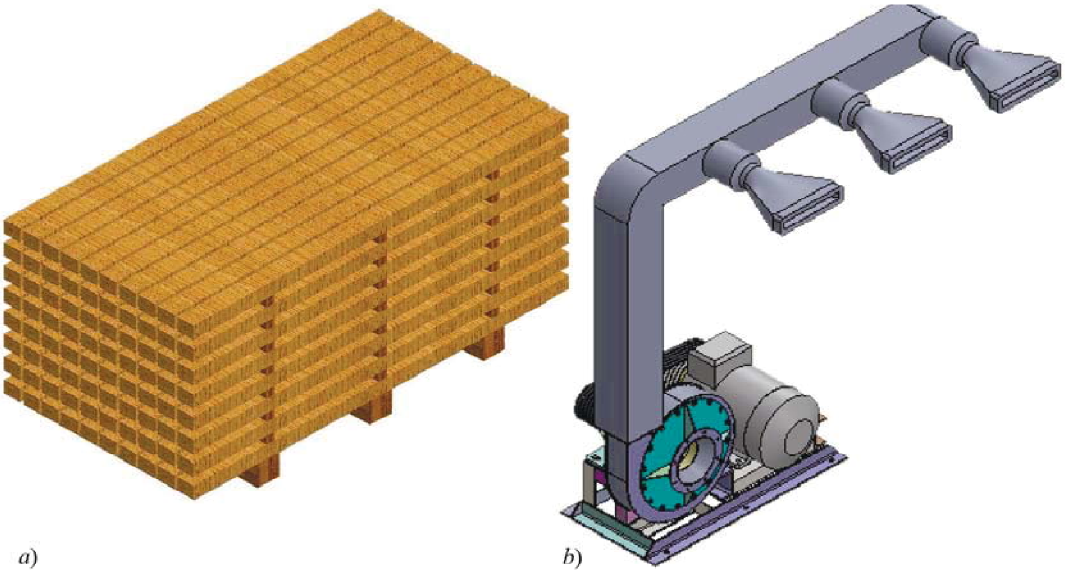

Fig. 2. View of stacks with 80 pieces of lumber / beams (*a*) and the system of fresh air supply to the wood drying chamber / Вигляд штабелів із пиломатеріалами / брусами кількістю 80 штук та системи подачі свіжого повітря до сушильної камери

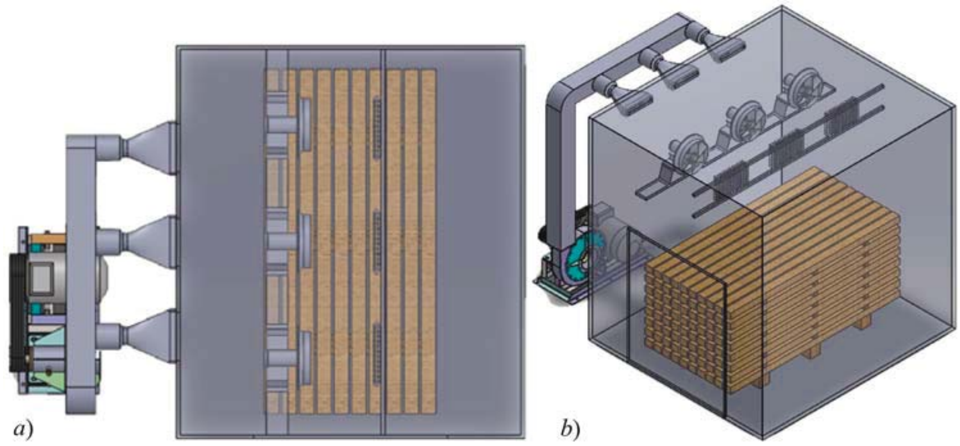

Fig. 3. View of the designed 3D model of the wood drying chamber / Вигляд спроектованої 3D моделі камери сушіння деревини: *a*) top view of the drying chamber / вигляд зверху сушильної камери; *b*) designed 3D model of the drying chamber / спроектована 3D моделі сушильної камери

In general, the user must specify the number of fans and heaters. By default, there are three units each. In addition, the chamber has metal partitions that imitate a false ceiling and are necessary for mounting fans and heaters. Another, perhaps the most important element is the stack of lumber, which is located on an under-stack truck (Figure 2,*a*). Another important element of the wood frying chamber is the fresh air supply system. In general, such a system can be represented by supply and exhaust ducts or specialized air supply systems. The latter consist of motors, ventilation ducts, and adjustable ventilation plugs (Figure 2,*b*). This type was chosen when designing this 3D model of the drying chamber.

It is worth mentioning that the designed 3D model of the drying chamber (Figure 3) is quite simplified both from the design point of view and in terms of size and scale. This was done to save time and resources that would have been significantly consumed in the case of designing detailed 3D models of drying chambers in real scale. The proposed approach significantly speeds up the process of computer simulation, which is especially important when a large number of computational experiments are performed.

Modeling of heat flows with different air velocity. This modeling can be performed using thermal analysis in SolidWorks Simulation. In this case, in addition to generating a mesh, the following modeling parameters must be set to conduct the study. First, it is necessary to set the distributed thermal resistance between the various elements of the drying chamber, in particular between the heaters and the stack. This can be done using the "Contact Set" component. Next, the heat source, which is the heaters, must be set. This can be done with the "Heat Power" component. It is also possible to set convection parameters to transfer some of the heat to the external environment.

To compare the heat flows in the wood drying chamber, it was decided to conduct two thermal experiments. The first was conducted with an air velocity of 2 m/s (Figure 4). As expected, this air velocity is quite sufficient for an even distribution of heat fluxes in the stack. At the same time, it was possible to achieve a slight temperature difference between the edges of the stack, which was approximately 3 degrees.

The distribution of heat flux was also investigated when the air velocity was increased, for example, to 3 m/s. In this case (Figure 5), the heat begins to spread faster along the stack, thereby speeding up its heating. At the same time, the temperature difference between the edges of the stack has not changed significantly and is still about 3 degrees.

Equally important from the point of view of analyzing the results is determining the temperature distribution in different places of the stack. To perform this task, we can use the "Prob" tool. The next step is to select points to determine their temperature values (Figure 6). In this case, the screen displays basic information containing data on the coordinates of the point location, its number on the finite element mesh, and the numerical temperature value in Celsius.

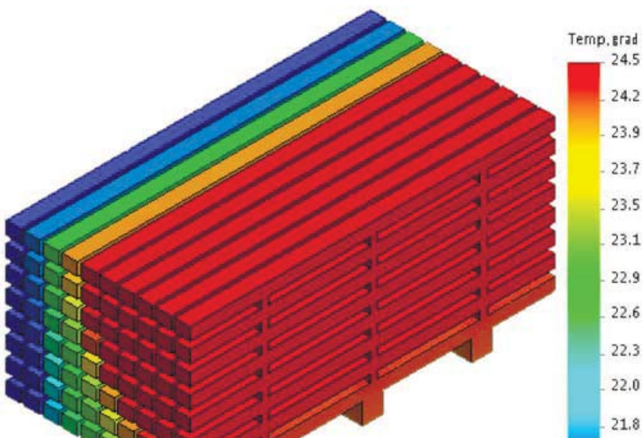

Fig. 4. Heat flow distribution across the stack with an air velocity of 2 m/s / Поширення теплового потоку впоперек штабелю зі швидкістю повітря 2 м/с

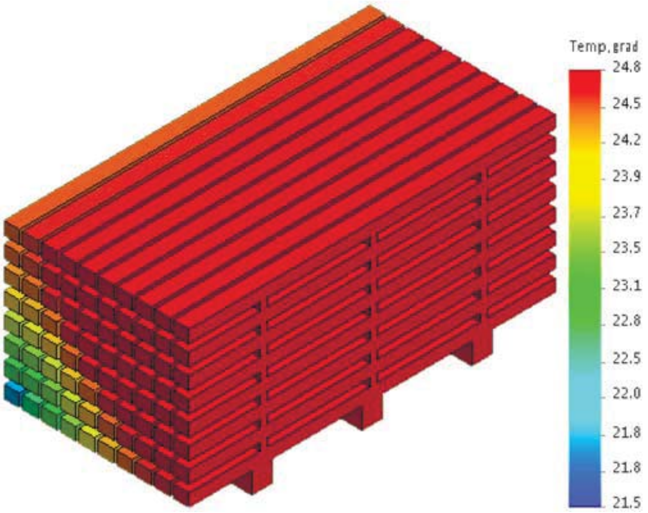

Fig. 5. Heat flow distribution across the stack with an air velocity of 3 m/s / Поширення теплового потоку впоперек штабелю зі швидкістю повітря 3 м/с

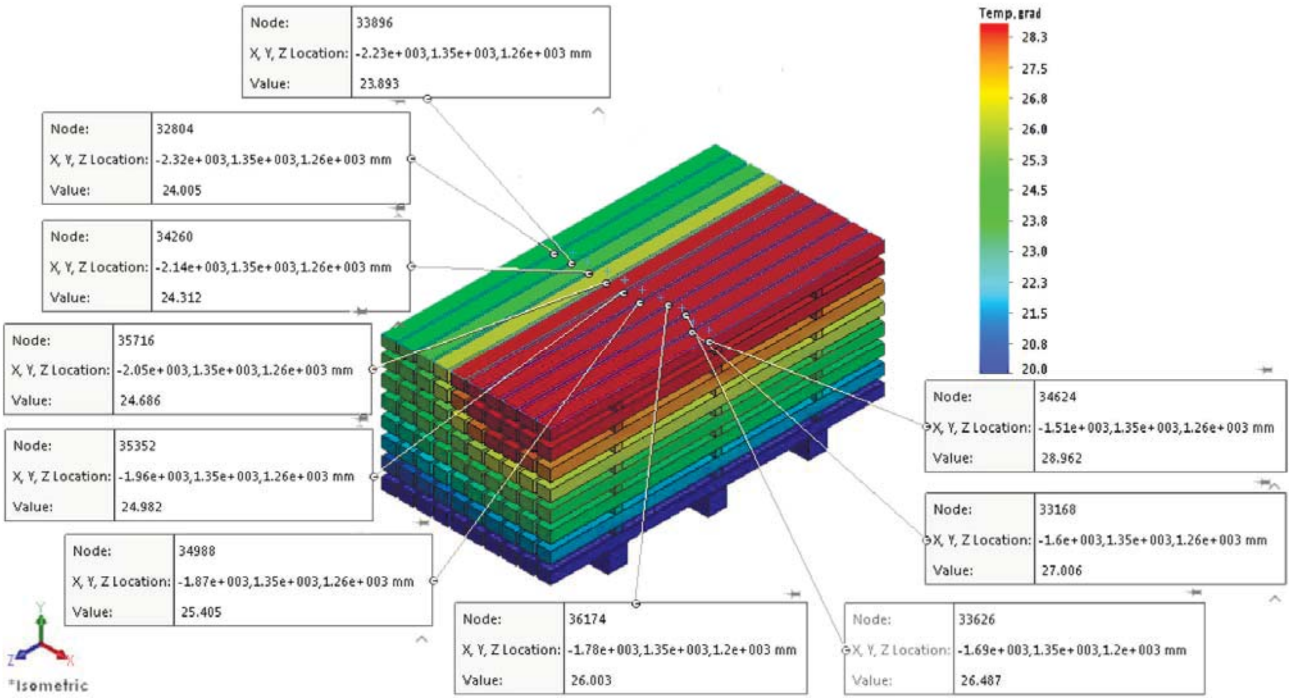

Fig. 6. Determining the temperature distribution in different places of the stack using the "Prob" tool / Визначення розподілу температури в різних місцях штабелю за допомогою інстурменту "Prob"

It is also possible to determine the temperature change along the entire stack. In this case, the temperature distribution of the stack was determined at its top and in the middle. The results show that at the top of the stack (Figure 7,*a*), the temperature has a strong difference in the places closest to the heaters. At the same time, in the case of the inside of the stack (Figure 7,*b*), this distribution is smoother and more uniform.

The obtained results clearly demonstrate the efficiency of the developed 3D model of the wood drying chamber and the possibility of further research on the physical processes occurring in it.

Developing specialized software using SolidWorks API. Recently, issues related to the development of specialized software applications have become increasingly important. Such applications provide solutions to applied scientific and engineering problems by integrating various software modules into a single information system. Integration of different applications is a task of particular complexity compared to traditional data integration. However, application-level integration has many more undeniable advantages. These include ensuring an end-to-end cycle of information interaction between applications; automated execution of service applications on command from the basic components of the information system; high performance due to the absence of the need for intermediate data formats; minimization of disk operations, etc. Therefore, one of the main requirements for the components of a modern information system for CAD, PDM or ERP is the ability to programmatically control the set of functional tools implemented in these components. In other words, the presence of an application programming interface, such as the SolidWorks API, in a particular application.

In practice, it turns out that while the capabilities of a conventional user interface are more than enough for designing products in a CAD system, to solve the problems of integrating applications at the level of a single information system, it is necessary to link different software products. Thus, the most important area of application of the SolidWorks API is the development of application modules that add additional functionality to the basic capabilities of SolidWorks in any special subject area, in this case, it will be automatic launch of experiments and display of results.

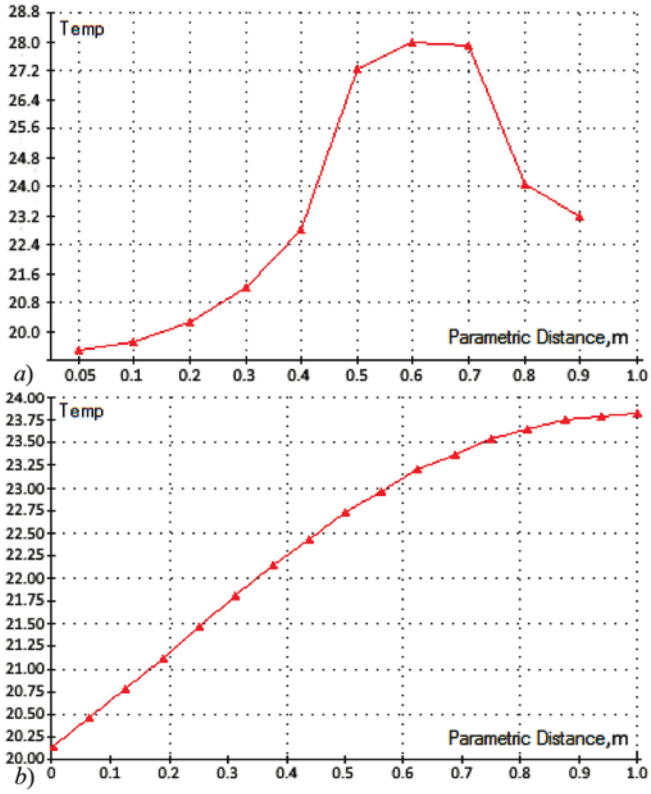

Fig. 7. Determining the temperature distribution across the stack on its top (*a*) and inside (*b*) / Визначення розподілу температури впоперек штабелю на його поверхні (a) та всередині (*b*)

In general, the software application was developed in the C# programming language and provides for the following tasks: change the geometric dimensions of the 3D model of the chamber (Figure 8), which allows to place a larger number of stacks; change of geometric and physical characteristics of the lumber (Figure 9) due to changes in its species, length, thickness and width; change in stack parameters due to changes in the size of the lumber, its quantity, and the height of the gaskets and pallet; entering input data for modeling and outputting results (Figure 10).

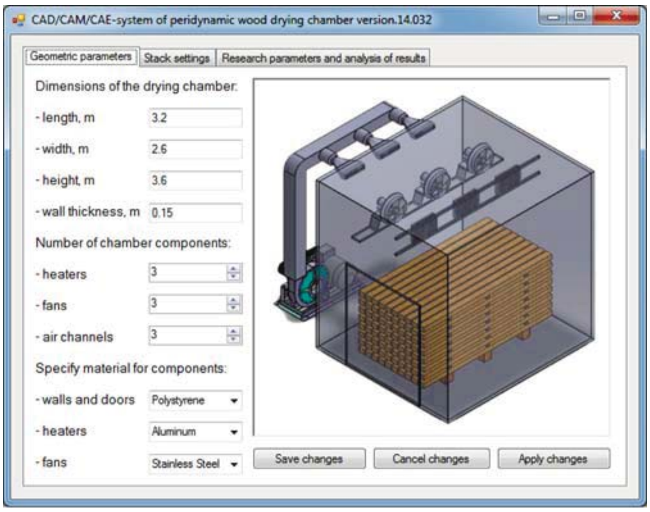

Fig. 8. Window for entering geometric parameters of a 3D model of wood drying chamber / Вікно введення геометричних параметрів 3D моделі сушильної камери

All of these actions are performed using the SolidWorks API, and the 3D model of the wood drying chamber that has already been designed. All changes were implemented by recording macros and their subsequent processing in the software. As for the modeling input data, the user can enter them at his own discretion, but by default they will be as follows: air velocity at 2 m/s, initial air temperature in the chamber and air at 20 °C. The air in the chamber is heated by heaters with a capacity of 2 kW.

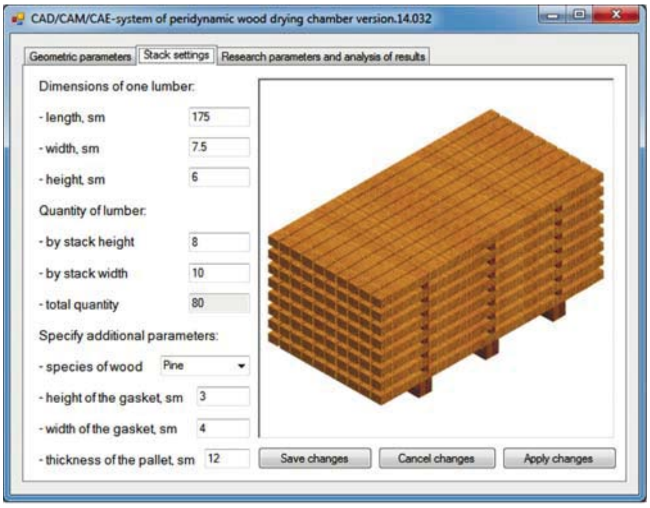

Fig. 9. Window for entering stack settings / Вікно введення налаштувань параметрів штабеля

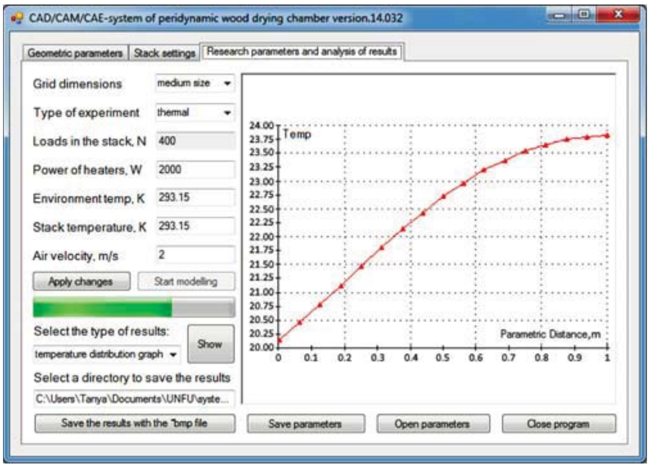

Fig. 10. The window for entering the parameters of the study and analysis of the obtained results of temperature distribution across the stack in graphic form / Вікно введення параметрів дослідження та аналізу отриманих результатів розподілу температури впоперек штабелю у графічному вигляді

By using the SolidWorks API, the input parameters of the modeling can be quickly changed, which makes it possible to obtain a variety of results. These results may be compared with each other, and the program provides the ability to save them on computer in the *bmp format.

Discussion of research results. In particular, many authors use SolidWorks Simulation to investigate various characteristics of wood, in particular by conducting static and thermal analyzes. For example, in [7] authors explore the enhancement of wood properties, particularly focusing on durability and mechanical characteristics, through the incorporation of wood composites with other materials using SolidWorks simulation technology. In turn, in [16] discusses the use of SolidWorks Simulation to evaluate the properties of birch plywood and compares the results with experimental bending and tensile tests based on LVS EN 789 standards. At the same time, the hydraulic features of the vortex flows in the drying chamber of the original design were studied in [6]. The use of the automated design and calculation system SolidWorks Simulation made it possible to analyze the movement of vortex flows, velocity fields and pressure drop of the drying agent, identifying opportunities for optimizing the drying process and developing efficient designs of vortex dryers.

Another interesting work is [13], which performs mathematical modeling and analysis of physical flows in drying chambers using COSMOSFloWorks design information technology. The SolidWorks computer-aided design system was used for solid modeling of the drying chamber and creation of three-dimensional models of its components. In addition, in [11], software was developed for the automated design of a 3D model of a drying chamber using the SolidWorks API. Several UML diagrams were created to model and visualize various aspects of the software, including classes, sequences, and usage. The software performance was tested by simulating the drying process of capillary-porous materials using pine as an example [1].

In work [15] problems during the verification of an integrated 3D project are considered. The authors believe that the integrated 3D configuration considered in this study includes a silicon die on one side of an organic interposer and a different die on the other side. The three parts are from three different design environments, each has its own database and description language not compatible with the other two. The incompatibility triggered a search for a new methodology for the physical verification of the 3D configuration. Application scripts were developed and successfully used to verify the physical connections within the complex design of the interposer, which accommodates 1600 signals and 12,000 traces for connecting the signals between the two chips. The layout of 56,000 vias for power and signal was also verified to meet the requirements for the manufacturing of the organic interposer.

All this work confirms the importance of such research. Comparing the results, it becomes obvious that computer-aided design and research of drying chambers has numerous advantages over traditional methods. This approach provides faster results at lower computational costs, as most operations are performed in the background. Overall, this study highlights the potential of automation and opens up prospects for future innovations in this area, which could ultimately lead to new and more efficient modeling methods [12].

So, based on the results of the work performed, it is possible to formulate the following scientific novelty and practical significance of the research results.

Scientific novelty of the obtained research result – the methodology of automated design and research of wood drying chambers, which combines computer modeling and engineering analysis, has been improved.

Practical significance of the research result – algorithms have been developed and implemented in the software that make it possible to carry out automated design and research of a 3D model of a wood drying chamber in the SolidWorks environment, completely in the background, thereby significantly saving time and computer resources.

Conclusions / Висновки

A 3D model of a wood drying chamber was developed and analyzed using the SolidWorks Simulation tool with automatic output of the calculation results and their graphical representation. Based on the results of the study, the following main conclusions can be made:

1. A new approach to the creation and analysis of wood drying chambers using SolidWorks Simulation is proposed.
2. A 3D model of a wood drying chamber was created, including the main components: a body, a fresh air supply system, fans, heaters, and a stack of dried wood.
3. Software was developed to allow automating the processes of designing and modeling 3D models of the drying chamber.
4. The heat flows occurring in the wood drying chamber were investigated.
5. The influence of air velocity on the heat distribution across the stack is analyzed.
6. It was found that the developed software can significantly speed up the process of designing and modeling a wood drying chamber.

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ВИКОРИСТАННЯ ІНСТРУМЕНТУ SOLIDWORKS SIMULATION ДЛЯ АВТОМАТИЗОВАНОГО ПРОЕКТУВАННЯ СУШИЛЬНИХ КАМЕР ТА ДОСЛІДЖЕННЯ ПАРАМЕТРІВ ЇХ РОБОТИ

Запропоновано сучасний підхід до автоматизованого проектування тривимірних моделей сушильних камер та дослідження параметрів їх роботи з використанням інструменту SolidWorks Simulation, що дає змогу створення різноманітних інформаційних моделей за допомогою комп'ютерних засобів. У роботі розроблено та представлено тривимірну модель сушильної камери, яка містить основні компоненти: стіни, перекриття, двері, штабелі із пиломатеріалами, що піддаються сушінню, систему подачі свіжого повітря, систему його циркуляції через вентилятори та обігріву через калорифери. Для автоматизованого проектування тривимірних моделей цих компонентів були також розроблені та програмно реалізовані відповідні алгоритми з використанням спеціалізованого програмного інтерфейсу SolidWorks API. При цьому, розроблений програмний додаток враховує введені користувачем параметри, зокрема розмір, кількість і тип пиломатеріалів, що піддаються висушуванню. Окрім цього, в роботі виконано кілька теплових розрахунків упоперек штабеля, зокрема із заданням різної швидкості руху повітря. Завдяки цьому було проаналізовано вплив цієї швидкості на розподіл теплового потоку впоперек штабелю. Загалом передбачено автоматичне відображення отриманих результатів в одному із вікон програмного додатку. Такий підхід дає змогу отримати результати у фоновому режимі роботи програми SolidWorks з мінімальним втручанням користувача. Незважаючи на те, що такі дослідження проводять у SolidWorks Simulation, отримання графічних результатів, зокрема розподілу температури впоперек штабелю, відбувається повністю в автоматизованому режимі без участі користувача. Також програмний додаток дає змогу автоматизовано змінювати геометрію тривимірної моделі сушильної камери чи штабелів у заданих межах. Використання розробленого програмного додатку спільно з SolidWorks Simulation дає змогу ефективно пришвидшити процес створення тривимірних моделей сушильних камер та вивчення параметрів їх роботи. Загалом ця робота відображає тенденцію до цифрової трансформації в промисловості, відкриваючи нові можливості для деревообробних підприємств і сприяючи підвищенню їх конкурентоспроможності на ринку та ефективності виробництва.

Ключові слова: тепловий розрахунок; 3D проектування; комп'ютерне моделювання; SolidWorks API; пиломатеріали; теплообмін; програмне забезпечення.