Energy Efficient Air Conditioning System of the Temple Complex

Anton A. Zharov*[(a)]*, Alexey V. Kasatkin [(b)]

(a) Bauman Moscow State Technical University, Moscow, Russian Federation
Moscow, 105005, Russia, zharov_a@bmstu.ru
(b) Bauman Moscow State Technical University, Moscow, Russian Federation
Moscow, 105005, Russia, kasatkinav@student.bmstu.ru

ABSTRACT

The purpose of this work is to develop a year-round energy-efficient air conditioning system for the temple complex, that meets modern engineering requirements and standards. And it should not violate the traditional appearance of an Orthodox church.
In this article there are considered the requirements and standards for the construction of the temple complex together with the architectural solution and the geographical location of the construction entity. The proposed air conditioning system (ACS) with a pneumohydraulic diagram and design modes is described. This system is valid for the summer and winter seasons. The main element of the ACS of the temple complex is an array of heat pipes. The efficiency of the installation is achieved, first of all, due to the recovery of soil heat in the annual cycle. In addition, efficiency is increased by utilizing the heat of the waste air stream and indoor recirculation systems. The article represents a constructive solution for the proposed heat pipe and its design modes of operation in the summer and winter periods together with the expected technical characteristics in different modes of operation, as well as design options for the upper heat exchanger. There is given the concept of the arrangement of the elements of the pneumohydraulic diagram on the cartographic plan of the building and their mutual correlation with the intensity of the operating mode for the soil. And the last, but not least, the article represents a simulation of the annual soil regime, calculated by the finite element method, performed in the ANSYS computational environment.

Keywords: Conditioning; Heat pipe; Regenerator of the annual cycle; Energy efficiency; Soil heat pipe.

INTRODUCTION

In our country, there are many destroyed churches, that have not yet been restored. Some of them are of cultural heritage sites, while others simply unload large temples being more accessible due to their location. Amongst other problems, during restoration, architects and engineers are faced with the difficulties of designing systems that maintain a comfortable indoor climate.The following requirements are imposed on HVAC installations for temple structures, in accordance with [3, 4]:

- Comfortable temperature in accordance with Russian Association of Engineers for Heating, Ventilation, Air-Conditioning, Heat Supply and Building

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Thermal Physics standard-2-2004 “Orthodox churches. Heating, ventilation, air conditioning"

- A moisture level that prevents mould and condensation from forming. According to existing standards, this is 40-55%.
- Lack of drafts and noise from the ventilation system.
- The elements of the ventilation system must fit into the church interior.

It is also required to solve some specific tasks, such as:

- The accumulation of people in the premises of the temple causes an increase of temperature and humidity, mould and mildew form on the walls and ceiling, damaging wall paintings, frescoes, icons and the building itself. Preservation could only be ensured within certain ranges of temperature and humidity.
- The upward architecture and complicated internal structure of religious buildings make ventilation and heating difficult.
- Soot and grime from candles and icon lamps damage the interior decoration of the temple and plaster.
- Besides, the developed system must meet modern standards, requirements and trends.

In particular, in connection with the rise in the cost of energy resources, the search for energy efficient solutions is becoming urgent. At the moment, the government is working actively to improve the energy efficiency of buildings, buildings and structures. This affects also the reduction of the permissible power consumption for heating, ventilation and air conditioning (HVAC) systems.

At the same time, the working substances of engineering systems must meet modern requirements for environmental safety, and in our case, when they can enter a building with a throngs of people. Together with this, the above substances must be non-toxic and explosion-proof.

Thus, the task of this work is to develop a year-round energy-efficient air conditioning system for the temple complex that should meet modern engineering requirements and standards. Besides, it should not violate the traditional appearance of an Orthodox church.

The projected ACS is intended for the temple complex located at the address: Moscow, Entuziastov highway, bld. 44.

THE PRINCIPAL UNIT

Pneumohydraulic diagram

To achieve this task, it is necessary to design a pneumohydraulic diagram and optimize it as much as possible. The designed diagram is shown in Figure 1. In accordance with the temperature conditions, let us divide the entire building into two levels. Let's start with the winter mode. The cold outside air must be pre-heated by a low temperature heat source (HPHE) [1, 2, 5, 7]. In this case it is soil with a temperature of about 8 °C. Further heating of the outside air is carried out in a recuperative heat exchanger (R) by utilizing the heat of the exhaust air stream, which has the temperature of the indoor air in the premises. Mixing the heated outside air with the recirculated air additionally brings the temperature of the supply air closer to the room temperature. The last stage is heating in a liquid heater (HL) [14].

In summer mode, hot outside air is cooled only by the soil (HPHE) and enters the room without recirculation, recuperation and heating [15].

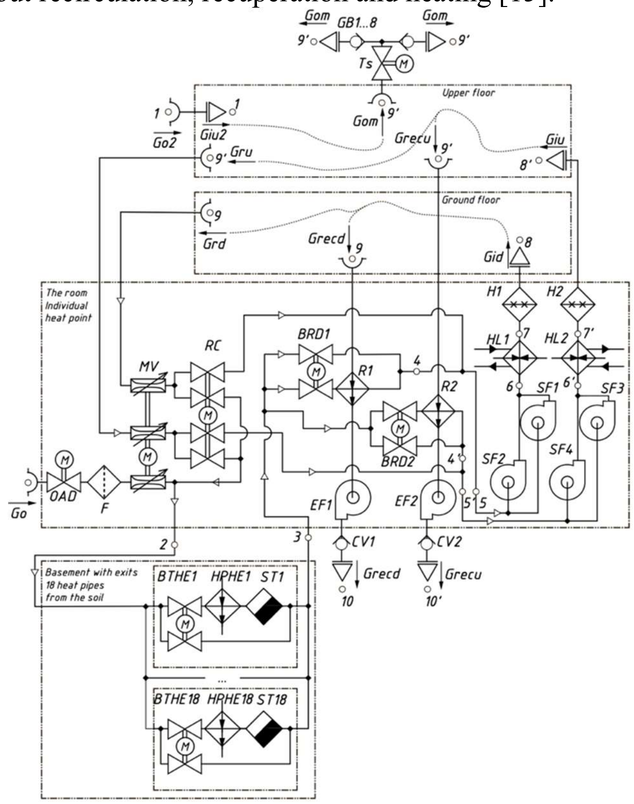

Figure 1. Pneumohydraulic diagram

OAD – outdoor air damper; F – filter; BTHE – bypass damper heat exchanger; HPHE –heat pipe heat exchanger; ST – steam trap; RS – recirculation switch; MV – mixer valve; BRD – bypass recuperator damper; R – recuperator; CV – check valve; EF – exhaust fan; SF – supply fan; HL – heater liquid; H – humidifier; Ts – transoms; GB – gravity blinds; Go – external air flow; Grecd – recuperation flow from the bottom of the building; Grecu – recuperation flow rate from the top of the building; Grd – recuperation flow from the bottom of the building; Gru – recuperation flow rate from the top of the building; Gid – supply air flow rate to the lower part of the building; Giu – air flow to the top of the building.

The main difficulty and the task of the project is the development of a device for transferring low-potential soil energy into the air stream. Let's call this device a heat pipe according to its function. Due to the low heat transfer capacity of the soil and the limited depth of soil use, a large usable area of land is required, therefore, the problem of connecting heat pipes must first be solved. It is decided to use multiple parallel heat pipes to increase the reliability and simplicity of the device. Figure 2 shows us the final heat pipe linking diagram.

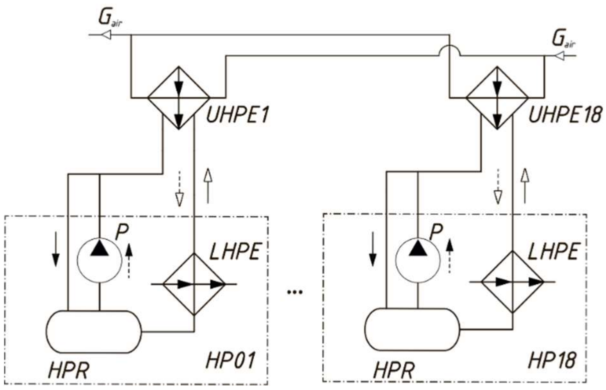

Figure 2. Heat pipe connection diagram

UHPE – upper heat pipe exchanger, LHPE – lower heat pipe exchanger, P – pump, HP – heat pipe, HPR – heat pipe receiver; Gair – air rate.

In winter mode, the refrigerant circulates naturally: the condensed refrigerant in the upper heat exchanger (UHPE) flows into the lower heat exchanger (LHPE) under the influence of gravity, where it boils off and rises up again. There is a problem in the summer mode of operation - the boiling of the refrigerant must be carried out in the upper heat exchanger (UHPE), and the condensation - in the lower heat exchanger (LHPE), while the liquid refrigerant cannot independently rise upward, even with the help of capillary forces, since the height of the heat pipe is several times exceeds the height of the capillary rise. This difficulty was solved by installing a submersible pump inside the heat pipe.

In addition to the chosen one, other schemes were considered, such as:

- Capillary rise into a single heat exchanger;
- Capillary rise to local heat exchangers;
- Steam lift system;
- Submersible pump with central heat exchanger.

The proposed scheme has the following advantages over others:

- simplicity of the diagram;
- simplicity of design;
- relatively low cost;
- short length of refrigerant (coolant) channels;
- higher reliability;
- if one pipe fails, the functioning of the rest is not damaged in any way.

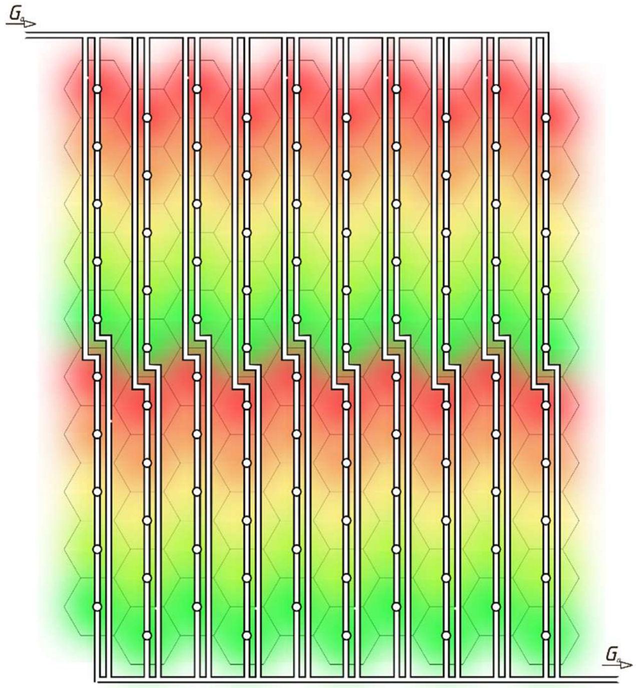

Figure 3. Interposition of heat pipes
Gair – air consumption

Figure 3 shows us the relative position of the heat pipes (they are marked with white circles) on the plan of the earthen area next to the temple. The lines indicate the duct linkage diagram, Ga - is the air flow rate. The color gradient depicts the intensity of soil work in the annual cycle (red - active use, green - practically non-working soil area).

Heat pipe construction

Figure 4 shows the design of a heat pipe. It is characterized by a long section of round pipe with a tapered end and a screwed bottom [8]. This element of the pipe acts as a lower heat exchanger (soil-coolant) [12, 13]. The upper part acts as the upper heat exchanger (coolant-air). It is inclined at 45 ° and equipped with plates, in order to intensify heat exchange with the air flow. In summer mode, to transfer fluid from the lower heat exchanger to the upper one, a liquid submersible pump and a spray diffuser are provided at the end of the hose.

The working substance is a R134a coolant. The estimated useful power (heating capacity) of one pipe in winter mode is 1,97 kW. In summer mode, the net power (cooling capacity) of one pipe is 1,83 kW. At the same time, in summer mode, a pump operates in each pipe. The pump's power consumption is 0,55 kW.

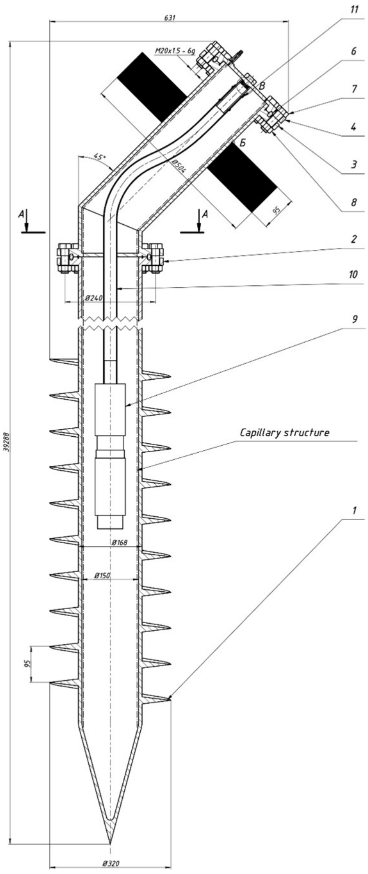

Figure 4. Heat pipe design
1 - end stop; 2 - outlet of the lower heat exchanger; 3 - upper heat exchanger; 4 - cover; 5 - pipe; 6 - gasket; 7 - bolt; 8 - nut; 9 - pump; 10 - PVC hose; 11 - clamp.

2.2.1 Top heat exchanger alternatives

Two versions of the upper heat exchanger were considered: with horizontal plates (shown in Figure 5 in summer mode, and in Figure 6 in winter mode) and with vertical plates of the snowflake type, shown in Figure 7 - in summer and in Figure 8 - in winter modes.

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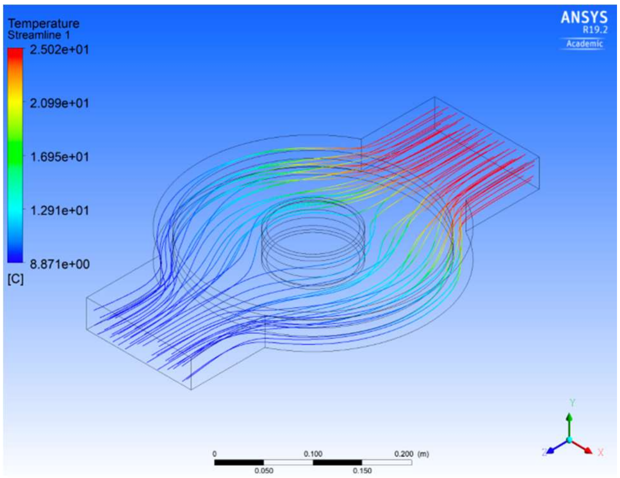

Figure 5. Upper heat exchanger with horizontal plates in cooling mode (the temperature of the cooled air at the inlet to the heat exchanger is 25 ° C)

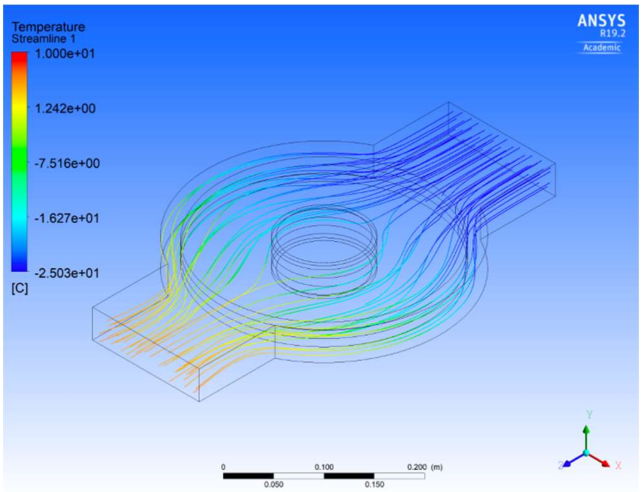

Figure 6. Upper heat exchanger with horizontal plates in heating mode (the temperature of the heated air at the heat exchanger inlet is 25 ° C sub-zero)

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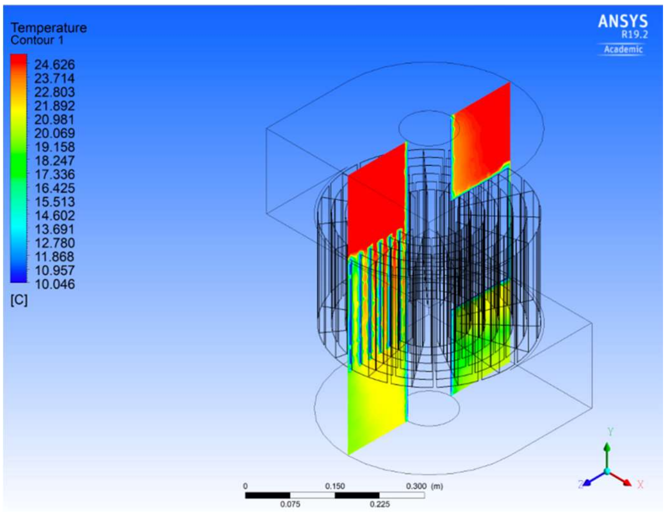

Figure 7. Upper heat exchanger with vertical plates in cooling mode (the temperature of the cooled air at the inlet to the heat exchanger is 25 ° C)

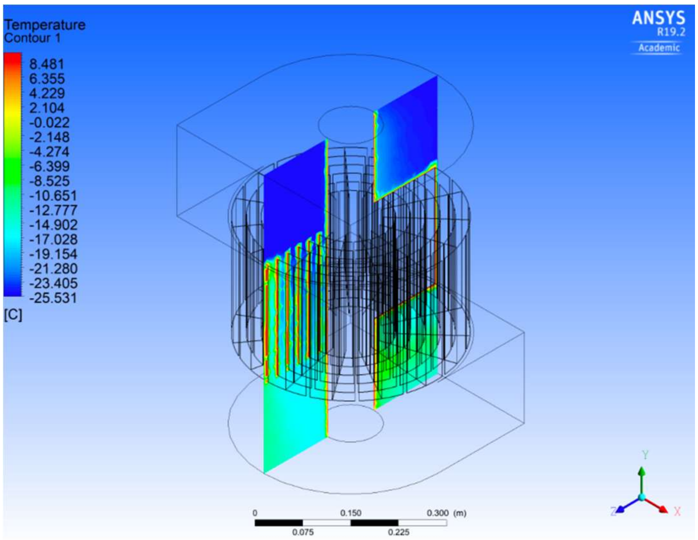

Figure 8. Upper heat exchanger with vertical plates in heating mode (the temperature of the heated air at the inlet to the heat exchanger is 25 ° C sub-zero)

It could be seen from the Figures 5-8, that a heat exchanger with horizontal plates has better cooling and heating approximately for two degrees. At the same time, the hydraulic resistance of the heat exchanger with horizontal plates is also significantly better.

2.2.2 Checking the annual soil operation by the finite element method

While using the proposed system, it is necessary to be sure that the reserve of heat capacity of the soil and its ability to transfer heat, would be enough for operation during the entire year, and, as well, in subsequent years in the same mode [6, 9, 10, 11]. The thermal regime in the soil was checked during the year, the control points of which are shown in Figure 9.

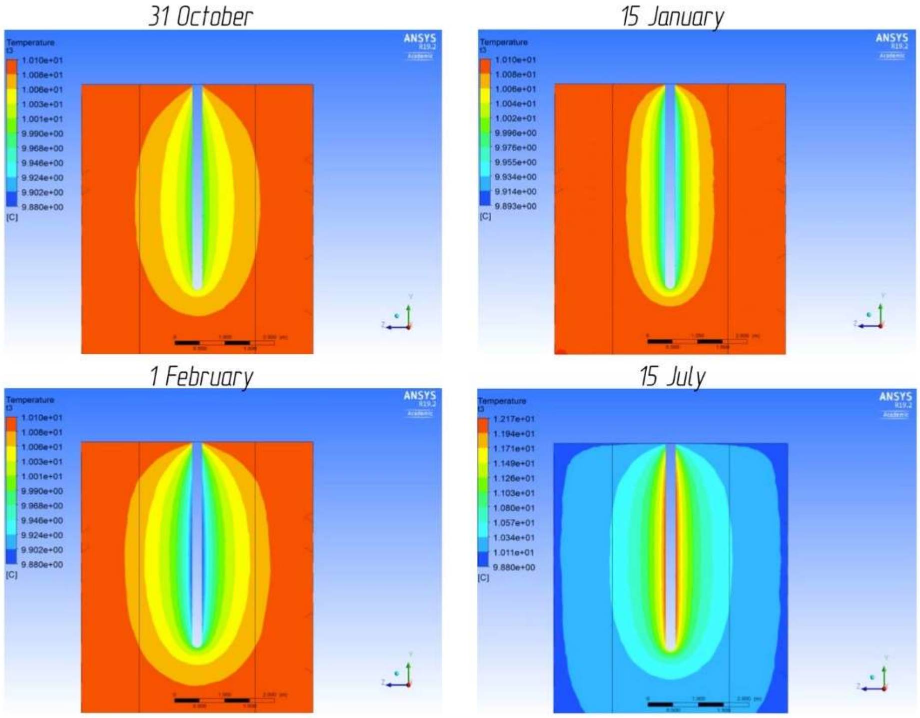

Figure 9. Distribution of temperatures in the soil layer from the lower heat exchanger throughout the year.

Figure 9 shows us that the temperature at the border of the working zone of the soil does not change and a stable temperature gradient is maintained throughout the entire operation time. So, it means that the heat capacity and heat transfer capacity are sufficient and the installation could be efficient.

CONCLUSION

The developed diagram and unit for it would allow to reduce the costs of the building's ACS, both in summer and winter modes. The diagram with thermal soil pipes requires large free areas, which also leads to large hydraulic losses along the air path of the outside air. However, this diagram allows one to minimize the cost of air cooling in the summer mode.

The developed heat pipe allows to implement the efficient operation of the system.

For the further research, it is proposed to adopt a safer coolant [16], in the limit of natural origin, as well as to simulate air flows in an air-conditioned space [17] and the natural experiment.

CONVENTIONAL SIGNS

OAD	outdoor air damper	SF	supply fan
F	filter	HL	heater liquid
BTHE	bypass damper heat exchanger	H	humidifier
HPHE	heat pipe heat exchanger	Ts	transoms
ST	steam trap	GB	gravity blinds
RS	recirculation switch	UHPE	upper heat pipe exchanger
MV	mixer valve	LHPE	lower heat pipe exchanger
BRD	bypass recuperator damper	P	pump
R	recuperator	HP	heat pipe
CV	check valve	HPR	heat pipe receiver
EF	exhaust fan		

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