

ENHANCING ROOF CONSTRUCTION TO IMPROVE EFFICIENCY OF DRYING

Emils Avots¹, Janis Palabinskis¹, Aivars Aboltins¹, Algirdas Jasinskas²

¹Latvia University of Life Sciences and Technologies, Latvia;

²Aleksandras Stulginskis University, Lithuania

emils.avots@inbox.lv, janis.palabinskis@llu.lv, aivars.aboltins@inbox.lv, algirdas.jasinskas@asu.lt

Abstract. Due to different conditions, this kind of collectors has not been implemented often. Firstly, it is an intervention in the roof construction, which requires changes to the projects, additional materials and expenses. Secondly, most importantly, the manifold absorbent material was not durable (damaged by sunlight, weather, birds, etc.) and over time became dirty and lost its transparency. Some of the disadvantages discussed above can be prevented by constructing a substructure that would capture the heated air under the roof of the hangar and direct it to the drying object. The design would be protected from precipitation, direct sunlight and birds. In this way, the heated air can be used to cool the grain or diverted to the furnace as a preheated air. The simple construction on the roof of the hangar shows that using such a design it is possible to increase the temperature of the usable air to 5 °C. The article offers a technological and technical solution for the use of warm air of the hangar for active ventilation of grain in the drying bin, which will significantly increase the efficiency of drying grain.

Keywords: roof construction, air heating, drying, efficiency.

Introduction

Modern new grain pre-treatment points, which are designed on the basis of heat and high-capacity grain storage bins, practically do not focus on the use of renewable energy. If renewable energy resources can be used as heat sources in renewable energy resources, then the use of wood resources for heat production is virtually impossible for other drying installations. The hangars, which are universal farm buildings were earlier recommended, but few realized, due to relatively short longevity to construct air heating solar collectors on the roof that could heat up the grain used for drying the air.

Solar radiation is an alternative source of energy for heat recovery for drying of various agricultural products, such as fruit, vegetables and cereal products. To get heat from solar radiation, solar collectors are used.

Wall and floor panels are used to heat production and other premises, which absorb solar heat and heat up the indoor air. This system is simple, efficient, inexpensive and environmentally friendly. Such a system is capable of providing fresh air and increasing the temperature of indoor temperatures by 5 to 25 °C above ambient air temperature, thus saving 20-70 % of fuel energy [1].

The territory of Latvia has a relatively low intensity of solar radiation. Its total solar energy is 1000-1200 kWh·m⁻² per year. Solar energy is a relatively reliable source of energy, and its disappearance is not forecasted in the future, and is actively used from small households to large factories [2].

It is known that atmospheric air, which is heated in solar collectors and similar equipment, can effectively be used to dry grain by raising the temperature to 15 °C, which means that, during days, solar thermal energy can be used efficiently without the use of fuel fueled heat generators [3]. Of course, such conditions for drying grain can be provided on sunny days, while the rest of the time it is necessary to use heat generators [4]. Solar collectors are widely used for electricity generation, but air heating is less common, although the design is relatively simple and inexpensive.

Collector insulation plays a large role in solar collectors for heating air. The collectors with insulated surfaces and uninsulated surfaces using thin steel plate as absorbent material warmed up atmospheric air by 10-12 °C and 5-6 °C, respectively, with solar radiation 800 W·m⁻² [1].

D. Fiaschi and A. Bertolli studied the heat generated from solar radiation from building roofs made of copper sheets with roof-mounted air ducts. It has been shown that by using well-designed geometry pipelines placed under a copper plate, it is possible to obtain an effective solar collector on the roof [5].

Many studies are devoted to drying of herbs and spices using the warm air extracted from roof-mounted solar collectors. These collectors function as the roof of a building.

The effectiveness of drying of different herbs and spices using roof-mounted solar collectors can reach 35 % per day. Such a solar collector roof also protects agricultural products from rain and insects, unlike drying agricultural products in the open sunlight field [6]. Similar studies have been done on drying of pineapples using a roof-mounted solar collector. After drying pineapples for 8 hours, the drying costs accounted for only 20 % of the cost, when drying was done using an electric drying machine [7].

Offering a roof-mounted solar collector it is possible to obtain a quality-dried product at a much shorter time than if these herbs are dried out in the field under the influence of solar radiation. The heated air is collected in the roof top and then further by the fan to the dryer. The payback time for this roof construction is approximately 5 years. The results of modeling simulation coincide with the performed drying experiments [8].

A roof-mounted air-cooled solar collector system is provided with heaters and fans, which can be used depending on the climatic conditions [9; 10].

The article deals with a simple warm-air collection system and its performance analysis to increase the temperature of the air supplied to the grain drying bin.

Materials and methods

The aim of this study is to make an air collector and to study the heat extraction using the air drawn from the hangar roof ridge. Studies were carried out on a farm. The hangar dimensions are 36x20 m with an area of 720 m². The hangar walls have a height of 5 m and a ridge height of 7 m. The outer walls of the hangar and the roof are covered with profiled metal sheets 1 mm thick. The roof sheet colour is dark brown. Due to the influence of the sun the roof of the hangar absorbs a large amount of heat energy, where the temperature in the ridge on sunny days can increase by 10 °C more than the temperature of the ambient air. During the experiment, in April and May 2016, the temperature of the metal sheet can exceed 40 °C, at solar radiation of 450 - 704 W m⁻².

In order to use the heat generated by the sun for drying grain, the warm air of the hangar is used on the farm, which is fed to the drying bin 13 (Fig. 1) next to the hangar with an isolated air channel 5, using a medium pressure centrifugal fan 9 that produces a pressure of up to 3 kPA. The fan productivity depends on the pressure caused by the grain layer, which is 35500 to 64500 m³·h⁻¹ [11]. The length of the insulated air transmission channel is 13 m and its diameter is 1 m, and it is connected to the hangar and the annex of the drying bin, thus delivering the air to the drying bin.

Before upgrading the roof structure, using a centrifugal fan 9 the warm air was directed from the hangar 1 through the insulated air duct 5 at connection 4 to the grain drying bin 13 (Fig. 1).

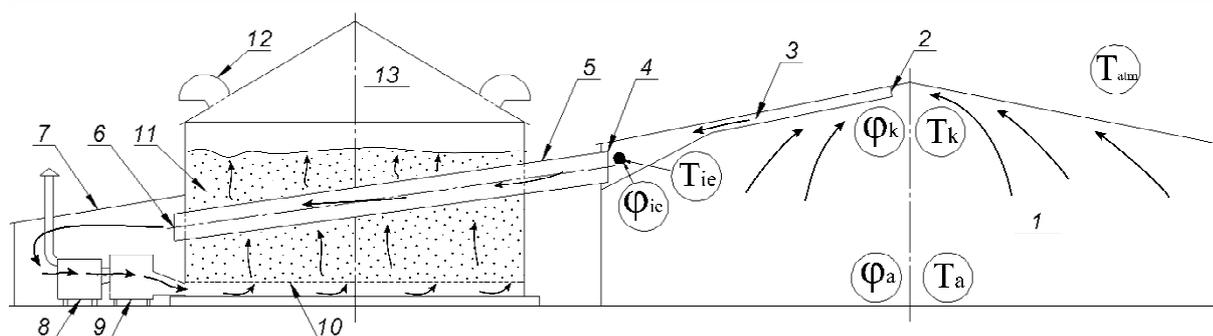


Fig. 1. **Airflow from hangar to grain bin with air collection channel:** 1 – hangar; 2 – inlet of the air collection channel; 3 – air collection channel; 4 – insulated air channel connection; 5 – insulated duct; 6 – insulated air channel connection at annex; 7 – annex; 8 – heat generator; 9 – centrifugal fan; 10 – perforated floor; 11 – grain layer; 12 – ventilation hatches; 13 – grain drying bin;
 T_k – air temperature in the hangar top; T_a – air temperature in the hangar; T_{atm} – ambient air temperature; T_{ie} – temperature in the outlet of the air collection channel; φ_k – air relative humidity in the hangar top; φ_a – air relative humidity in the hangar; φ_{atm} – ambient air relative humidity; φ_{ie} – relative humidity in the connection between insulated duct and air collection channel

With the help of smoke and the fan turned on, it was found that warm air near the roof of the hangar does not reach the entrance to the air collection channel 4. Therefore, an experimental lightweight construction hot air collection channel was constructed below the roof 3 (Fig. 1, 2), collecting warm air from the hangar's ridge. When temperature of the roof rises, the warm air moves along the roof to the ridge. By creating an air collection channel 3, it is possible to collect heat from the hangar ridge for drying, which is heated by the sun.

Wooden laths of a size 5 x 5 cm and a polyethylene film 0.2 mm thick are used for the construction of the air channel (Fig. 2). The size of the air channel is 9.7 x 2.7 x 0.5 m and area is 23.23 m². The size of the inlet of the air collection channel is 2.7 x 0.5 m with area 1.35 m². The design of the air collection channel is stable, light and does not pose a large load on the roof structures of the hangar.



Fig. 2. Air collecting channel covered with polyethylene film: 1 – air collection channel; 2 – connection between the duct and air collection channel

For air temperature and air relative humidity measurements wireless temperature and humidity meters were used such as KLIMA-MONITOR (measurement range for temperature 0 °C to +60 °C, air relative humidity 20-99 % and accuracy respectively ± 1 °C and ± 5 %) and Wireless Thermo-Hygrometer (measurement range for temperature -40 °C to +60 °C, air relative humidity 10 to 99 % and accuracy respectively ± 1 °C and ± 5 %).

The radiation from the sun was determined by a solar radiation meter Power Meter STANDARD ST-1307 (measurement range 0-1999 W·m⁻² and accuracy 10 W·m⁻²).

The study carried out measurements of the relative humidity of the air temperature T and air in the hangar of φ (Fig. 1) at a height of 1 m from the floor T_a and φ_a , at a distance of 30 cm from the roof cover T_k and φ_k , at the entrance to the insulated air passageway T_{ie} and φ_{ie} and atmospheric air outside the hangar T_{atm} and φ_{atm} .

Results and discussion

The studies were carried out in the spring of 2016 in the months of April and May. Measurements of the air relative humidity and temperature were made with the fan turned on in sunny time, so that the clouds do not significantly affect solar radiation. To show the degree of heated air, measurements were compared with the temperature in the hangar at a height of 1 m from the floor. The results are summarized in Fig. 3-6.

Figures 3 and 4 compare the air temperature difference without using and using an air collection channel. Comparing the results the temperature of the collected air for drying in the air collection duct is only 2-3 °C lower than in the ridge T_k , while without the duct it is even lower by 8 °C (Fig. 4). Without using the air collection channel, the average temperature difference between the hangar ridge T_k and the hangar's air T_a is high, from 5.8 to 8.8 °C, resulting in incomplete use of warm air in the ridge (Fig. 3). The temperature difference between the insulated air channel entrance T_{ie} and the hangar T_a is relatively small, from 0.6 to 1.1 °C, so the benefits of the sun's influence on the heated air

atmosphere in the hangar is minimal. In turn, the average solar radiation during the experiments ranges from 450 to 620 $\text{W}\cdot\text{m}^{-2}$.

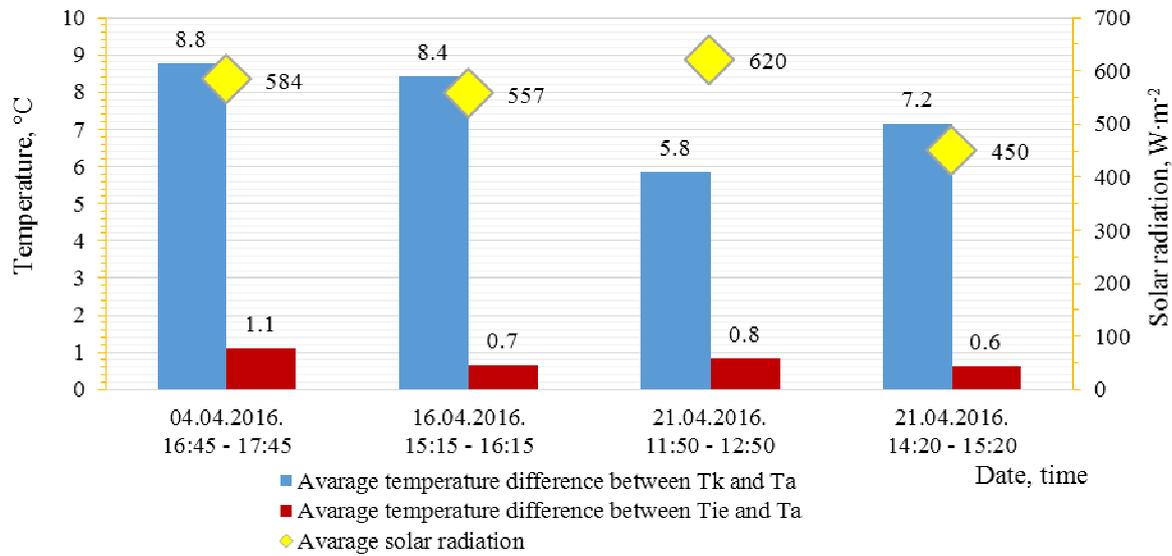


Fig. 3. Comparison of average temperature differences without using air collection channel

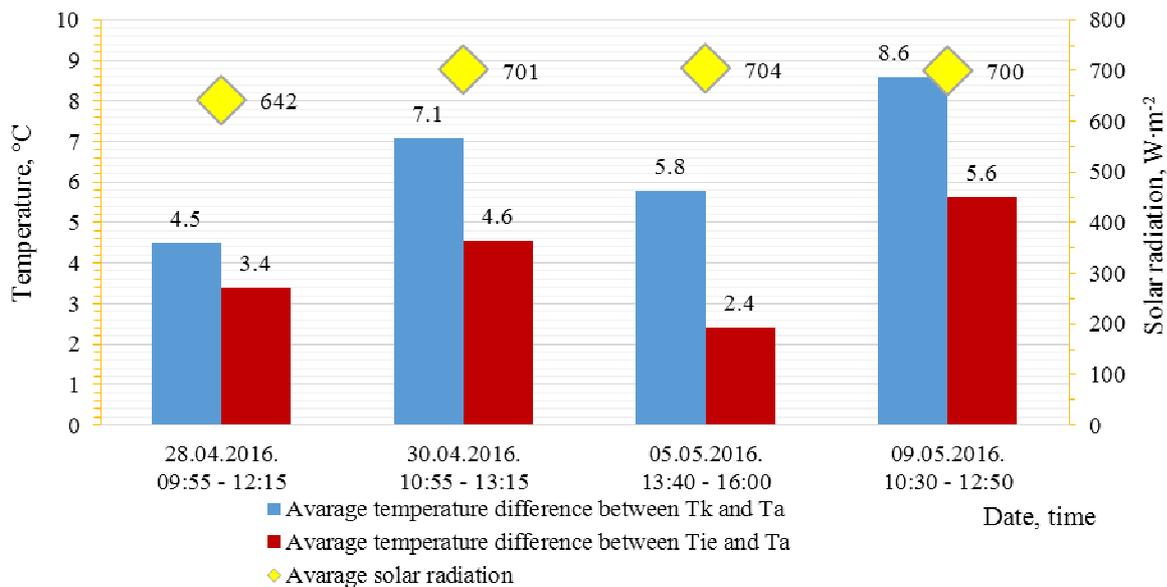


Fig. 4. Comparison of average temperature differences using air collection channel

Using the air collection channel, the temperature difference between the air collection channel entrance T_{ie} and the hangar T_a has increased by an average of 3.2 °C, and on some days this difference exceeds up to 5 °C (Fig. 4). This means that warm air is collected more efficiently from the ridge of the hangar, where its temperature is higher. In addition, the temperature difference between the ridge of the hangar T_k and hangar T_a is lower, which is an average of 6.5 °C.

In addition, the influence of the weather conditions during the measurement is also to be taken into account, since, as shown in Fig. 3 and 4, the radiation of the sun was by 642 to 704 $\text{W}\cdot\text{m}^{-2}$. Atmospheric air and air in the hangar are warmed up, so there is a lower temperature difference between the ridge of the hangar T_k and the hangar T_a .

Similar to the temperature differences, the relative humidity of the air between the ridge of the hangar φ_k and the hangar φ_a is high, which ranged from 21 to 28 % during the experiment, without

using the air collection channel. This means that the humidity of the hangar ridge was more than 20 % less than the hangar.

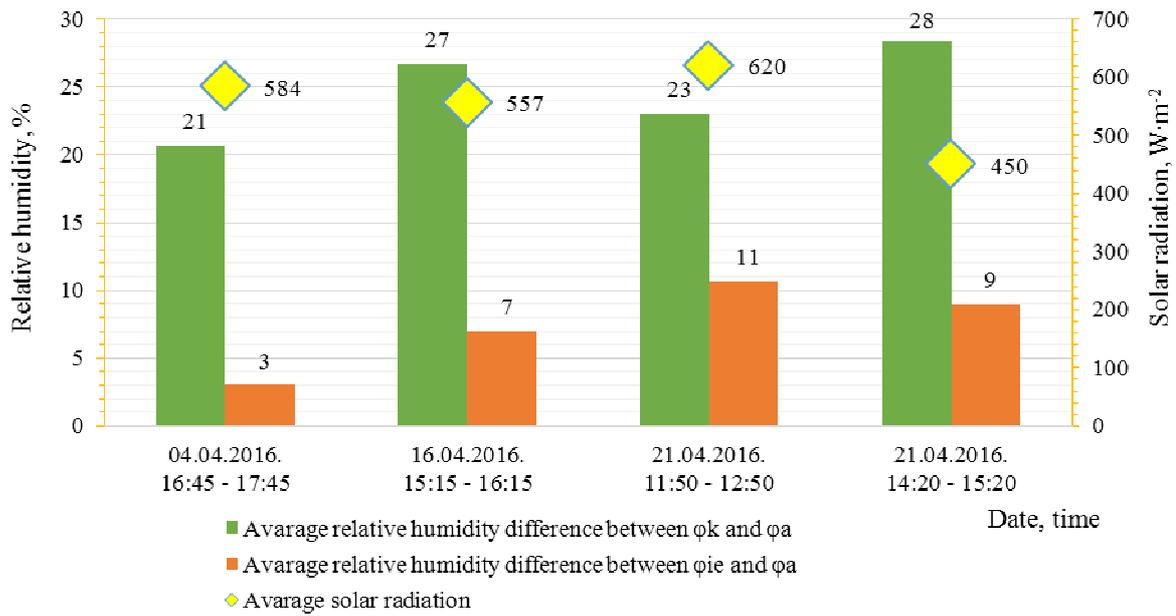


Fig. 5. Comparison of average relative humidity differences without using air collection channel

However, the relative humidity of the air at the entrance to the air channel decreased slightly, as the relative humidity of the air between the hangar φ_a and the inlet of the air collection channel φ_{ie} was observed, although the temperature difference was observed only at 1 °C. This effect can be explained by the air flow generated by the fan, because the airflow can significantly change the air parameters.

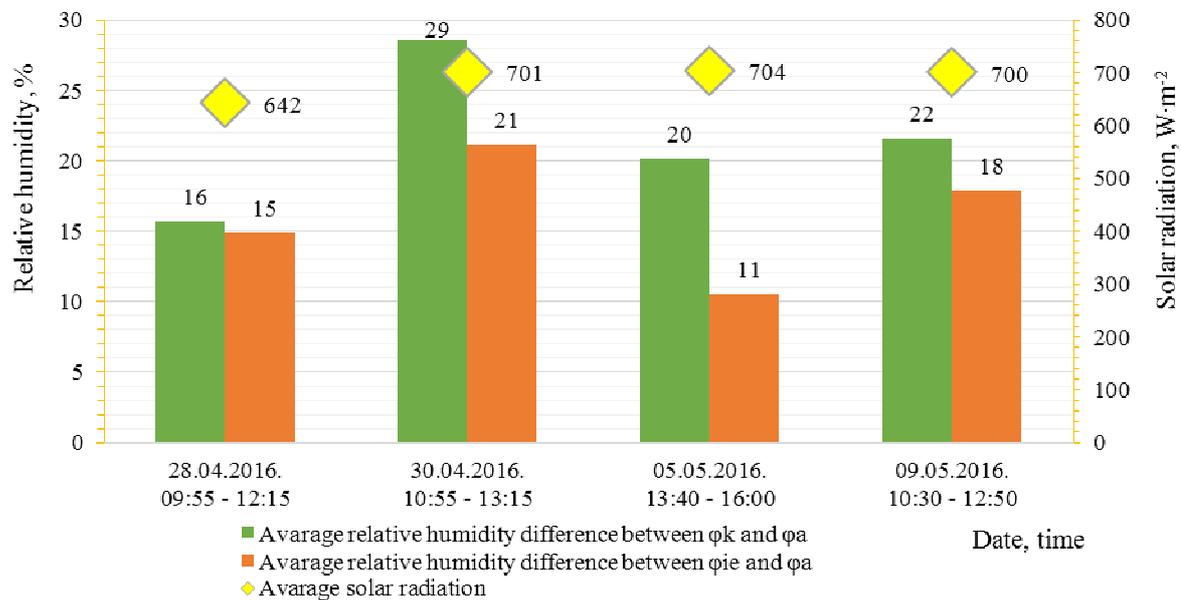


Fig. 6. Comparison of average relative humidity differences using air collection channel

Using the air collection channel, it was observed that the relative humidity of the air between the ridge of the hangar φ_k and the hangar φ_a was between 16 and 29 %, which means that the relative humidity in the ridge φ_k was still lower than in the hangar, just as in the previous measurements carried out. During these measurements, solar radiation was also slightly higher, on average from 642 to 704 W·m⁻².

In contrast, the average temperature difference between the inlet of the insulated air channel T_{ie} and the hangar T_a increased with the use of an air collection channel, which means that air from the ridge of the hangar is collected more efficiently and directed to the grain dryer. This is illustrated by

the difference in air relative humidity between the insulated air channel inlet and the hangar, which in this case ranged from 11 to 21 %. Compared to Fig. 5 air relative humidity differences, it can be seen that it is possible to reduce the relative humidity of air by about 2 times and to use it better for drying of agricultural products (Fig. 5, 6), using an air collection channel.

Assuming that the drying air temperature is increased by 4 °C using an air collection channel, the amount of heat that was saved is calculated and compared with the fuel consumption, where the amount of heat generated by diesel is $4.14 \cdot 10^7 \text{ J} \cdot \text{kg}^{-1}$. It saves 332.8 MJ of energy equivalent to 8 kg of fuel oil per hour. So, using a warm air collection channel that increases the incoming air temperature by 4 °C, it saves 9.6 liters of diesel fuel during one hour of drying.

Conclusions

1. Using a simple air collection system, the internal air temperature of the hangar can be used more effectively during the drying process. In good weather conditions, the temperature of the drying can increase up to 6 °C.
2. Using the air collection duct, the fuel consumption for heating the drying air temperature decreases by 9.6 liters per hour.
3. Wider use of solar energy with simple equipment can make a significant contribution to energy efficiency, especially in processes that require high-energy intensity.

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