

EXPERIMENTAL BIOMASS DRYER

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Abstract

Purpose: to relate the outcomes of an analysis of the new MSc. field of study at the State Agrarian University of Moldova (SAUM) and consequent proposal and construction of a solar-powered Biomass Dryer as an integral part of the Bio-energy Lab. This represented a major part of an educational development project, which aimed at formulation of New MSc. Study Programmes. In accord with the Bologna requirements for higher education in Europe, the project strives for an alignment of the SAUM programmes with European Union standards.

Methodology: An extensive survey of activities linked to teaching programs was conducted. The methodology was based upon a logical sequence of steps, starting (first) with the evaluation of the current situation through to the (final) proposal for the curriculum, proposed to be used in the new fields of study within the Master of Science programmes. In this context, a proposal for a Bio-energy Laboratory was formulated. The experimental facility was then built and put into practice, with the Biomass Dryer being a critical part of the overall system.

Findings: the Biomass Dryer was designed and built strictly for educational and research purposes. It was intended to be used for the storage and drying of the biomass, whereby alternative drying processes were planned. The solar collector comprises the upper part of the roof (upper transparent cover and lower blackened panels) and heats the air which is then passed into the dryer.

Practical implications: the Biomass Dryer is of a unique design which can be easily modified to make the drying process of the biomass possible in different locations. According to the Dublin descriptors, all master programmes must be supported by facilities that enable both master and doctoral candidates to conduct their research and experiment activities. By building the solar-powered Biomass Dryer to the original specifications, and making it an integral part of the Laboratory, the drying of the biomass can be maximised prior to any further processing (briquetting, pelleting).

Key words: bioenergetics, solar energy, biomass dryer, biomass

INTRODUCTION

The development of bio-energetics at the beginning of the new millennium creates new demands on research in the field. Solid fuels made of vegetal biomass present an alternative to fossil fuels like coal or natural gas used in stationary heating facilities. With the prices of energy constantly rising, the use of biomass presents an option for decreasing energy dependency. There is also another advantage, which should be taken into an account: locally produced biomass contributes to self-sufficiency and a lower dependency on the energy market and on other regions and countries. It provides more favourable economic conditions in terms of energy supply as well as social advantages by creating local job opportunities. There are two alternative sources of biomass: (1) biomass grown specifically for energy use and (2) secondary biomass based on the wastes from agriculture, forestry and landscape management. Preferred energy crops are herbaceous species such as miscanthus, fescue grass, energy grasses, energy sorrel and others. Sorghum and

maize (corn) are also used for these purposes. There is a rapidly increasing tendency to use ligneous species as well, particularly poplar, salix and acacia. Aside from these energy crops, there is a vast range of phytomass sources which are residues from fodder, food and industrial crops. The use of cereal straw, rape straw, waste product from orchards and vineyards is currently under discussion.

As for any phytomass, it is always necessary to meet two essential conditions for its energy use: a sufficient amount of the mass and desired quantity. With this in mind, the energy crops grown specifically for energy use are expected to yield high levels of usable biomass. The quality is measured primarily by its water content. The lowest water content (ideal condition) is at harvest time (or after a period drying in the field) as is in the case of energy sorrel, cereal and rape straw. Other crops must also be dried to enable their long-term storage.

There are several reasons why the low water content in the biomass is important: long-term storability increased heating value and further easier processing. The main

reason is the biomass long-term storability. The plants' organic life declines when the water content falls to 38%. The decomposing microbial processes cease to exist with water content under 20% (Sladky, Hutla, 2000). A research project was conducted of the storage of fine wood chippings (dime approx. 1 cm) of poplar and salix stored in heaps (Kanswohl et al., 2006). A rapid increase of temperature – up to 60°C – was detected in a “non-ventilated” sample, which was due to excessive microbial activity. Over three months, the water content decreased from the original 57% to 45%, however, the mass losses reached 30%. The other reason is that with the decrease of the water content the heating value of the fuel grows. It also makes the further processing of biomass into biofuel (briquettes, pellets) easier.

The drying of plant materials in layers on grids is the most common way of water content reduction, mostly used in large-scale hay-barns. The process of drying consists of blowing air into the under-grid space. For this the values of aerodynamic resistance were researched (see Figure 1). The Figure 1, which is attached in the appendix, indicates values of air pressure losses penetrating a layer of wooden poplar chippings with different sizes of particles (Hutla et al., 2005). The numbers of samples, characteristics of the sizes of material are shown in Table 1. The above findings were further applied in the research of the biomass drying process conducted at the Research Institute of Agricultural Engineering (RIAE) in Prague. There, large-scale hay-barns with original grids and fans were used for drying the poplar chippings. The fans were controlled in three driving cycles which made the assessment of the levels of electric energy consumption possible (Hutla, Sladky, 2001). The biomass was sufficiently dried within three days (in sunny weather conditions). The drying potential of the energy sorrel (in the form

of chopped forage) was studied in the same way (Hutla, Mazancova, 2004). It was discovered that sufficient reduction of water content takes place in the span of about 20 hours. As the conclusion was based on the above described experiments, use of the existing large-scale hay-barns was endorsed (Hutla, Sladky, 1999). There were approximately 1 600 such hay-storage facilities in the Czech Republic at the time of the experiments, with a total of storage capacity of 10 million m³.

For smaller-scale farms, light buildings with a solar roof are recommended for drying and storing the energy chippings. The process of drying is reinforced by solar heating of the drying air (Oberhuber and Simader, 1999). The air is then distributed through sub-grid channels and penetrates the dried material.

MATERIALS AND METHODS

In order to be able to create an effective Masters' programme implementation at SAUM (State Agrarian University of Moldova) in Chisinau, an extensive survey of its facilities related to the teaching programmes was launched (Diagram 1). Its methodology was based on the sequence starting (firstly) with the evaluation of the current situation and ending (lastly) with the final proposal for the new M.Sc. study fields.

The purpose of the Laboratory of Bio-energy was to support the Masters' courses by providing facilities which would enable M.Sc. and PhD students to conduct experimental activities. The Laboratory was built and equipped in line with the newly formulated programmes of M.Sc. study courses. For this purpose, the Laboratory includes equipment for biomass processing (chopping, milling, graining), production of shaped solid bio-fuels (briquettes, pellets), equipment for testing boilers, and research of bio-fuel energy content. The Solar Dryer, which is the subject-matter of this article, was projected as essential part of the Laboratory; it stands at the beginning of the experimental chain. It was designed to be a light building equipped with fans and air channels in which (on grids) the material is to be dried in heaps. The drying air is heated either by heat exchangers (heat from the warmed up water) or by sun (roof made of transparent poly-carbonates) or by both of them combined, and then forced by fans into the air channels.

The air penetrating the heap of biomass must be suitably processed in order to assure its high water absorption capacity. The air passing through the biomass to be dried absorbs water released from the vegetal material. The air absorption capacity is ensured by its low humidity content, i.e. the difference between its humidity and the limit of water saturation (full saturation of the air with water

Tab. 1: Characteristics of poplar chippings for different samples

Sample 1	Processed data	
	fraction d (mm)	medium size d _s (mm)
1	0–10	5.0
2	0–15	8.29
3	0–20	10.66
4	0–80	15.39
5	10–15	12.70
6	15–20	17.50
7	20–25	22.50
8	25–40	32.50
9	40–80	53.33

vapour at the given atmospheric pressure). The relative humidity is the magnitude which describes air humidity in the relationship to the limit of saturation. The following **equation (1)** approximately gives the magnitude:

$$\phi = \frac{p_{vp}}{p_p} \quad [\%] \quad (1)$$

Where:

p_{vp} – partial water vapour pressure [Pa]

p_{vp}^2 – partial water vapour pressure at the saturated status [Pa]

Thus, the partial pressure of the saturated water vapour is the maximum pressure at the given temperature. This pressure is dependent only on the temperature (Neuberger et al., 2007) and grows with the growing temperature which, by consequence, causes a decrease of the relative humidity “j”. If we express the partial pressure of the water vapour “ p_{vp} ” by the stated equation for dry air and water vapour (together) we get the formula (2).

$$p_p = \frac{x \times p}{0.622 + x} \quad [\text{Pa}] \quad (2)$$

Where:

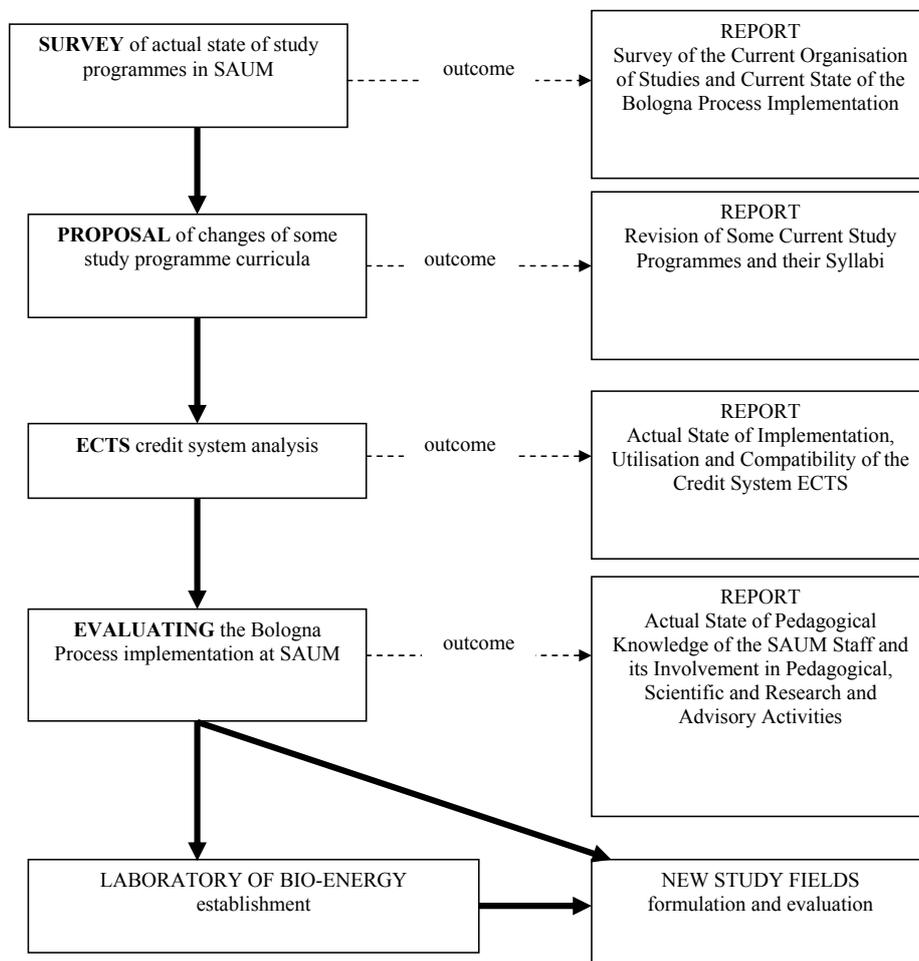
p – atmospheric pressure [Pa]

x – specific mass of the water vapour in given amount of the air [kg/kg dry air]

It is evident (from equation 2), that the partial pressure of the water vapour “ p_{vp} ” is (in difference to the partial pressure of the saturated water pressure “ p_{vp}^2 ”) not dependent on the temperature and characterises the mass of water in the air in a given time. The dependence of “ p_{vp} ” on temperature can be proved by tables of water vapour (Neuberger et al., 2007).

It can be considered (for the drying purposes) that the lowest possible relative humidity by which the air could absorb the most water from the biomass when being dried, and the drying process, could be shorter. There are, in fact, three basic conditioning systems of the air delivered into the Dryer. Under conditions when the air relative humidity is low (ideally under 50%) such air can be immediately (directly) used. The other variant is warming up the air in a warm water exchanger. The last alternative is the use of a simple solar collector in-

Diagram 1: Methodology algorithm



tegrated into the roof of the Dryer. Under the climatic conditions of Moldova (similar to those of Czech Republic) the direct use of outside air (without additional conditioning) is possible only in some short periods of the year (in principle in summer). The air relative humidity in winter varies between 75–90%. Lower values of relative humidity occur in the transitive periods (spring, autumn) – about 60–75%. The lowest values of relative humidity are during the summer months when its daily values are 45–65%. It is quite evident that the direct use of outside air is possible during the summer and some parts of transitive periods. However, the choice of the most convenient air humidity depends on the beginning moisture content of the dried biomass and required period of drying.

The most simple air humidity conditioning can be through its warming up. During air warming under constant pressure, increase of its temperature and decrease of its relative humidity takes place. Other criterion of humidity – specific mass of water vapour [kg/kg dry air] remains constant.

It is necessary to pass the air through the biomass being dried which can be ensured by the use of fans. Their main parameters can be determined by two basic conditions: speed of the drying air coming out from the layer of the biomass (about 0.1 m/s). This value is similar to the hay drying in large-scale hay-barns. The air pressure loss due to its passage through the biomass depends on its structure. If the biomass is in the form of energetic chippings or chopped fodder the pressure loss depends on the size of particles (Figure 1). If the biomass layer thickness will be about 2 m, than at average size of chippings 10 mm, the pressure loss will be about 80 Pa.

RESULTS AND DISCUSSION

On the basis of the requirements and methodological pre-requisites, an experimental Dryer was planned and built on the campus of the State Agrarian University of Moldova in Chisinau. In Figure 2 the overall view on the equipment is shown. The Solar Dryer was built against the wall of the laboratory building. The roof of the Dryer is, in fact, an air solar collector for warming the air which is passed into the Dryer. Inside the Dryer there is a space for depositing the dried biomass. This space is separated from the main laboratory building by a narrow corridor in which are placed the fans which force the warmed air into the Dryer.

The principal diagram of the Dryer (its transversal section) is shown in Figure 3. The outside air is drawn through the solar collector (1) by means of fans (3). Passing the solar collector the air is warmed up. It is then

passed into the corridor in which the fans can be found (2). The fans push the air through the heat exchanger (water – air) (4) into the air divider (5) and further into floor channels (6). From the channels the air penetrates into the biomass (7) being dried by the air. After having passed through the biomass, the air returns out into the atmosphere. The entire Dryer is composed of three sections. The overall ground-plan of the Dryer and its main dimensions are shown in Figure 4. Each of drying sections comprises a ground-plan area of 24 m². If the biomass layer is 2 m (projected), the drying of 48 m³ of material can be considered; three sections all together provide a drying capacity 144 m³.

The solar roof has an area of around 90 m². It consists of an upper transparent part made of polycarbonate panels and a lower part which is covered by black paint. This part absorbs solar radiation. Both parts are separated by wooden beams which create air channels (the section of the channels are 100 × 15 cm). The space between the beams and both parts of the roof is used for the passage of air which is warmed up there. The detail of the roof is shown in Figure 5. The roof inclination is about 9°, its orientation is to the north-east.

Each fan has a nominal flow capacity of 8 640 m³/h; i.e.: altogether for three sections 25 920 m³/h. The type of fans are AVET 630H/500E (manufacturer: Jindřich Kadlec – Stroje a zařízení), they have a prolonged cylindrical diffuser which covers the rotor and motor placed in its axle. There is a protective grid at the air suction side which protects the operator from contact with the fan spade wheel. The nominal power of the electric motor which drives the fan is 1.5 kW. For experimental purposes, the Dryer is driven through frequency changers which enable a continuous change of fan speed (thus the amount of air delivered). The frequency changers used are SINAMICS G110 (manufacturer: Siemens AG), and they enable a possible change of rotation speed in the range 0-100% of nominal values. The fan is connected to a three-row warm water heat exchanger – type CIC H10 (manufacturer: C.I.C. Jan Hřebec, Ltd.). Its nominal power is 57.9 kW at the temperature gradient of the heating water 90/70°C and water flow 2.5 m³/h. The air (at its flow of 8 640 m³/h) can be warmed from 20°C to 40°C. The placing of fans with their exchangers in the corridor is shown in Figure 6. The air divider passes the air into 3 floor channels in each section. The length of each is 5.5 m. The channels are of rectangle shape 300 × 320 mm; they are covered by grids 300 mm wide (manufacturer: CanAgroc, Ltd.). In Figure 7 there is a view of one of the drying sections. The air divider can be seen against the front wall, and in the floor there are air channels. The load force of the channel grid is 6 tons which enables use of heavy machines inside the dryer.

There is an accessible source of heat for heating the water passed into the heat exchangers – it is the biomass boiler with a nominal power 49 kW. A type KTP 49 biomass boiler (manufacturer: ROJEK dřevobráběcí stroje, Joint-stock Comp.) was used for this purpose. This power is just enough for one heat exchanger, and for the work of one drying section. If all the three sections should be in operation, the above power will be divided. At the actual power (as shown above) the temperature change (increase) will be 290.2°K higher (if only one section works); however if all the sections are being heated, the temperature change (increase) will only be 278.7°C. In winter time, when the relative humidity of the air is the highest, it is realistic to reach only 278.2°K and relative humidity 22%, if operating one section (if, for example, the outside temperature were -12°C and relative humidity $\phi = 90\%$). By this, the drying of the biomass can occur under very good conditions, producing high quality biomass suitable for further processing.

Also, when all three sections are in operation, the reduction of relative humidity can be remarkable, too (down to 54%). This outside temperature occurs, however, in only a couple of days per year – it is more typical for the temperature to be around “zero” and the relative humidity about $\phi = 80\%$; thus the resulting air relative humidity is 25% (at one working section) and 53% (at three sections). The results are very similar to the above winter calculated conditions, because this starting point (state) is close to the limit of saturation ($\phi = 100\%$). During the summer run, however, the values of relative humidity may only be 22%. The resulting states are closely behind the 20% curve of relative humidity (Figure 8). The result of these very similar values achieved in winter and summer is due to a very high partial pressure of the saturated water vapour for higher summer temperatures (see **formula 1**) and higher specific mass of the water vapour in the air (see **formula 2**).

In some periods of the year (on sunny days) the solar collector can be used for heating the drying air. The collector is integrated into the roof of the Dryer. The solar radiation which is collected by the device is not totally utilised. The efficiency is lower than the collectors for water heating (with the liquid transferring media). This is due to the losses at the low temperatures of outside air. The cause is the relatively simple device construction. The efficiency of air collectors are about 15–45%. In Table 2, some solar radiation parameters are shown, and from them are derived the heat power parameters of the collector. The values are split on some months of the year. The energy gains of this solar collector are relative low when compared with the conventional (liquid media) collectors. Despite the low power, the collector essentially improves the drying air parameters, especially when its parameters are not suitable for an effective drying process. In the case of one section in operation it is possible to increase the air temperature by about 3.2°C (in June) with consequent decrease of the air relative humidity by about 15%.

CONCLUSIONS

The experimental Biomass Dryer was built for research and educational purposes. It enables simulations of some drying processes under different regimes (parameters) and measurements of technical parameters and properties of dried materials. It is also an important part of the Laboratory because it enables long-term storage of different vegetal materials. On the basis of the above facts it is possible to make conclusions and give the following recommendations:

There was an effort to make use of large-scale hay-barns for storage of energetic biomass which was dried there. It was concluded that the original equipment (grids, fans)

Tab. 2: Theoretical and actual heat power of the air collector

Month		1	2	3	4	5	6	7	8	9	10	11	12
Average monthly intensity of solar radiation (Kabele et al., 2008)	[W/m ²]	61	104	179	254	318	345	328	275	202	126	72	49
Theoretical power of the solar collector per one section	[W]	1830	3120	5370	7620	9540	10350	9840	8250	6060	3780	2160	1470
Calculated efficiency	[%]	15	15	20	25	25	30	30	30	20	20	15	15
Actual heat power of the collector (one section)	[W]	275	468	1074	1905	2385	3105	2952	2475	1212	756	324	220

can be utilised for drying biomass. This action confirmed that the above equipment could be used.

The concept of an original Biomass Dryer was developed and built in the campus of State Agrarian University of Moldova. The Dryer has an integrated solar collector which enables saving energy whilst drying biomass. The Dryer can store different kinds of biomass. This material can be boosted (dried) by means of air flow blown

through underground channels, the air being heated by solar radiation and/or warm water.

The solar collector integrated in the drier roof is unique, and enables solar heating of the drying air to be used.

It is recommended to make use of the Dryer for educational as well as research purposes. However it can be modified and built in various designs usable in different geographical zones.

ANNEXES

Figure 1: Aerodynamic resistance of the layer of poplar chips; layer 1 m thick with different size of particles. Numbers of samples, characteristics of the sizes of a material are in Table 1.

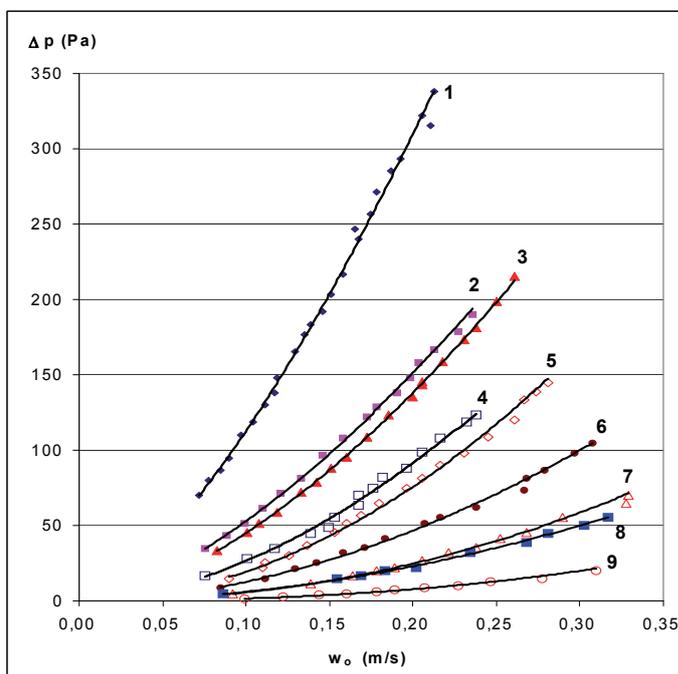


Figure 2: Experimental Biomass Dryer – overall view



Figure 3: Principal diagram of the Dryer (transversal section)

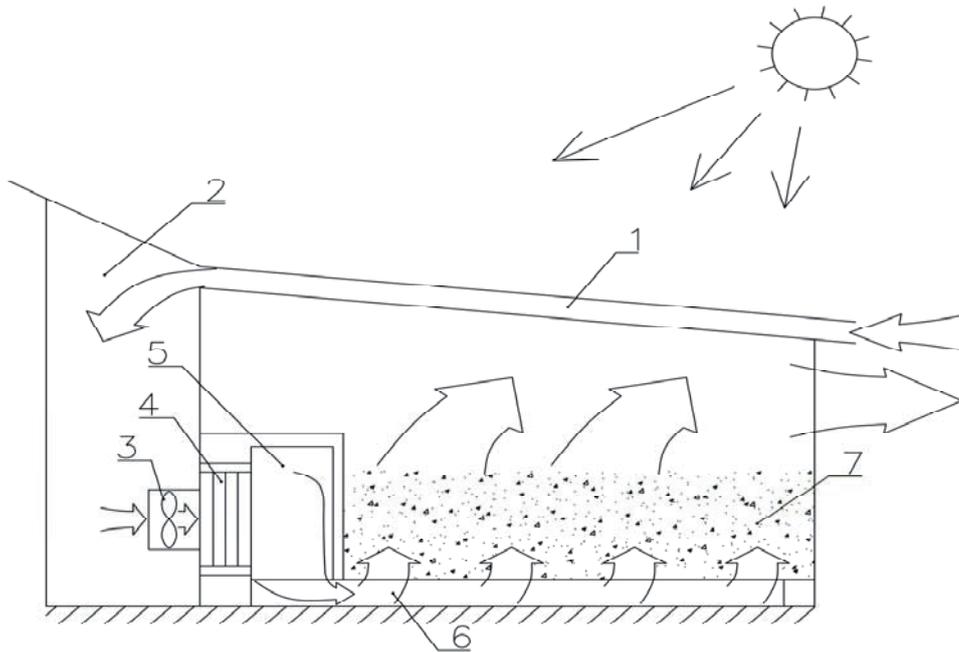


Figure 4: Experimental biomass Dryer – groundplan

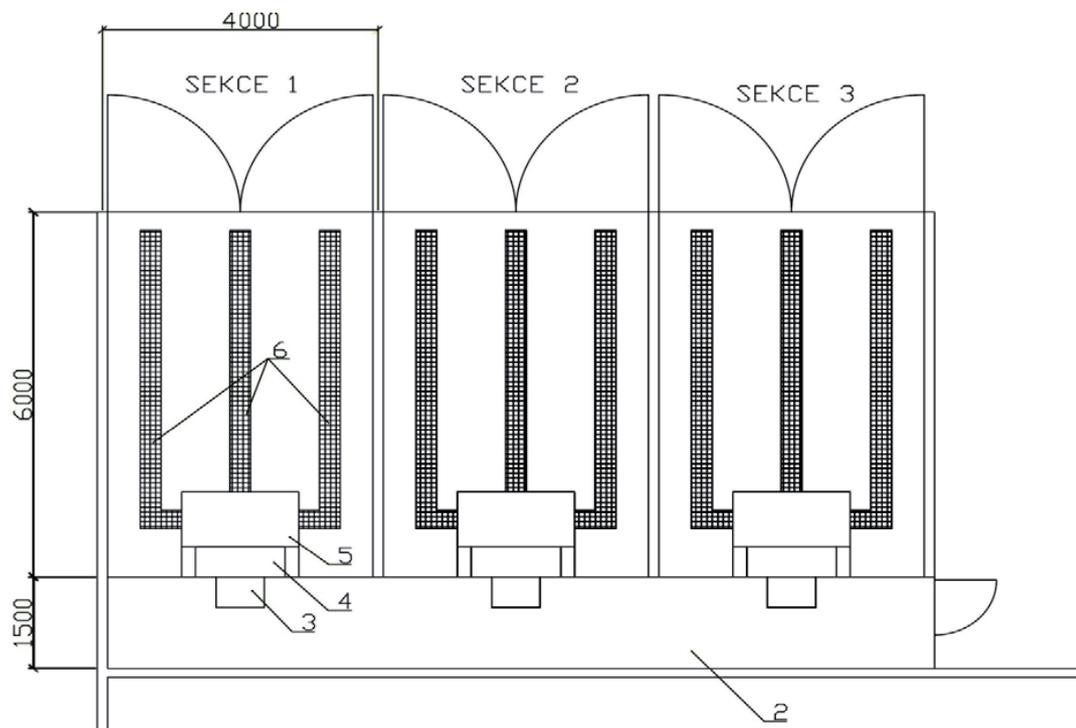


Figure 5: Roof construction in detail



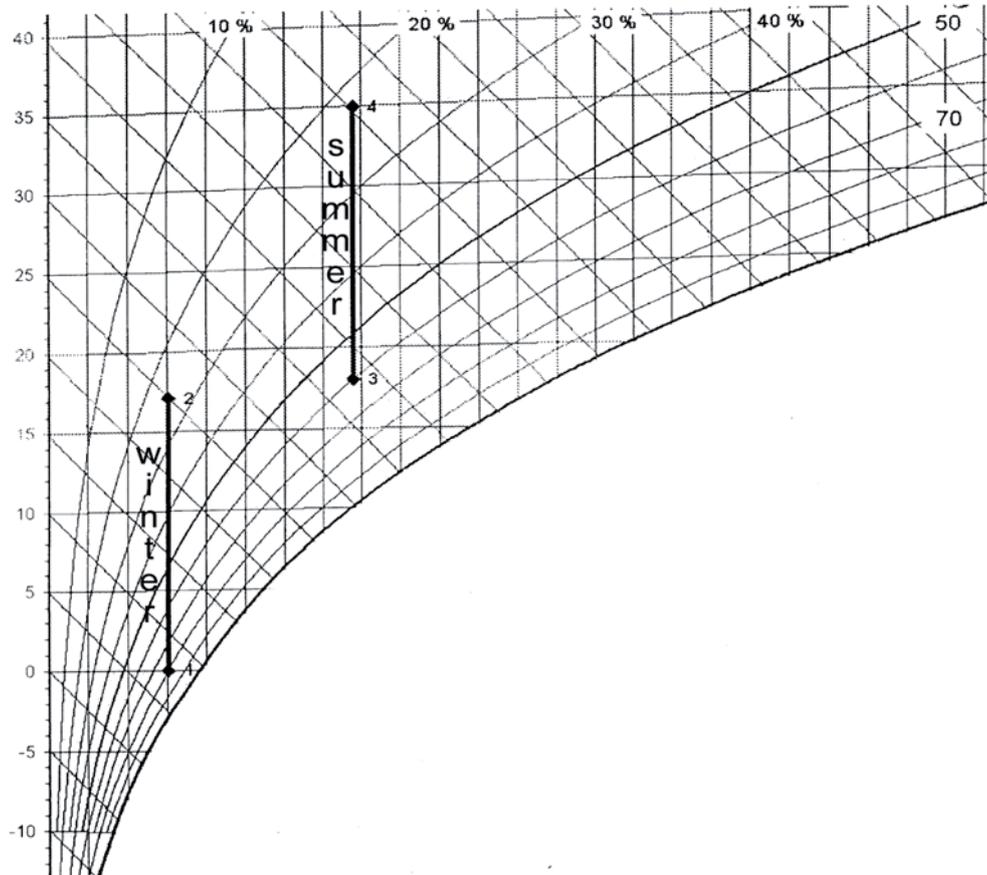
Figure 6: Placing fans with assembled heat exchangers



Figure 7: Internal space of one drying section with air divider and floor channels



Figure 8: Principle of heating in h-x diagram



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