Industrial applications of the air direct-contact, gravel, ground heat exchanger

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Abstract. The paper describes the analysis of possibility of using the air direct-contact, gravel, ground heat exchanger (Polish acronym BGWCiM), patented at the Wroclaw University of Science and Technology to prepare air for conditioning rooms in the industry. Indicated the industry sectors where the application may be the most beneficial.

1 Introduction

1.1 Reasons for raising the issue

The urgent need to save energy obliges to more widespread use of solutions enhancing generation of natural energy which exists in nature and is easily accessible. One of methods to use it is the air direct-contact, gravel, ground heat ex-changer (Polish acronym BGWCiM), tested thoroughly at the Wroclaw University of Science and Technology and the advantages of which will be presented. Industry is one of the most important sectors of a national economy. It is worth mentioning that together with agriculture and construction, industry consumes nearly half of all energy produced. Heavy industry has got an important share. In the processing industry, most of the energy is consumed by the food, chemical, mineral, steel and paper industries [7]. Greater efficiency in the use of energy in the economy, and especially in the industrial sector, has got a significant impact on production costs, profits of enterprises, as well as competitiveness of their products on the world market. It also contributes to faster development of enterprises.

1.2 The air direct-contact, gravel, ground heat exchanger

For many years, research has been carried out at the Institute of Air Conditioning and District Heating of the Wroclaw University of Science and Technology on efficient capture of natural heat (and also cooling) from a small depth of ground, in the air direct-contact, gravel, ground heat exchanger for ventilation and air conditioning purposes [1–3].

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In the exchanger, the outside air is led horizontally through a 3–5 m long accumulation bed (fig. 1) [1]. Following the contact of the air flowing between the filling of the bed, its temperature is brought closer to the filling's temperature, which during peak load results in heating of the outside air in winter from -18°C to about 0°C, and cooling it in summer from +30°C to about +20°C.

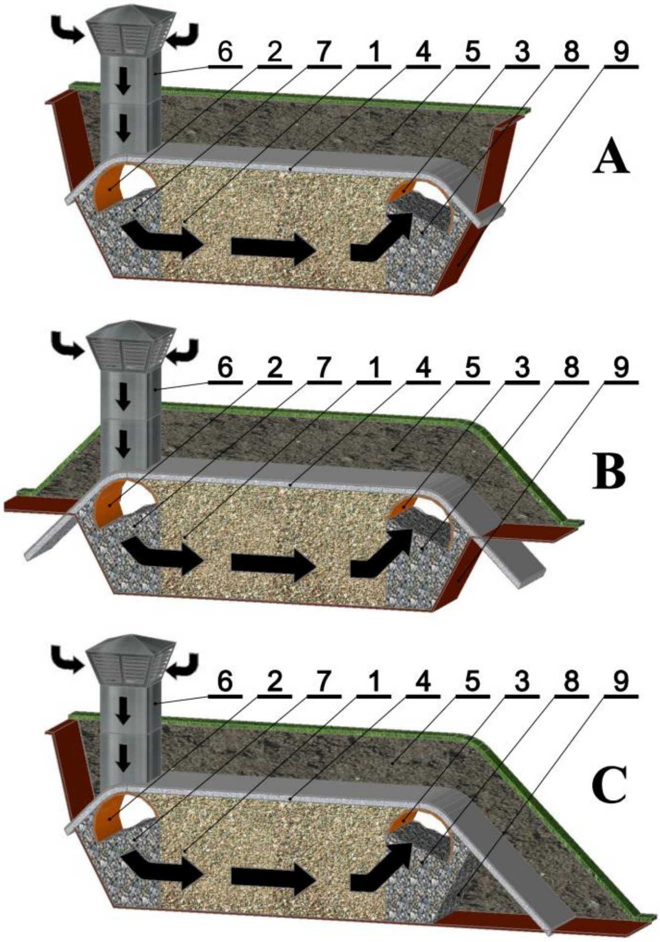

Fig. 1. Various proposals for the exchanger construction: A – recessed, B – partially recessed, C – elevated above the level of the existing terrain and situated on the slope, 1 – accumulation bed, 2 – distribution channel, 3 – collecting channel, 4 – thermal/humidity insulation, 5 – exchanger cover, 6 – air intake, 7 – distribution bed, 8 – collecting bed, 9 – natural ground.

Experience has shown that the accumulation bed should be made of washed gravel, gravel or rock grit having a hydraulic diameter of 15–40 mm but without fractions smaller than 3 mm. Stones having a hydraulic diameter of 80–100 mm constitutes a distribution layer. Thermal/humidity insulation should be made of 10 cm polystyrene protected with two layers of double foil. The entire area should be covered with about a half-meter layer of soil in order to enable planting of shrubs or lawn cultivation.

The heat exchanger (distribution and accumulation beds) should not exceed 5 m length and 2.5 m height. Studies have shown that continuous operation of a 5 m long bed during a summer day results in an optimal shift of a heat wave in the filling. As a consequence, lowest temperatures of the air leaving the exchanger are achieved at the highest outdoor temperatures [1, 2].

The nominal air velocity, depending on operating mode, may range from 0.05 to 0.20 m/s. Such values result from the heat and mass exchange conditions be-tween the air and the filling, as well as from resistance of the airflow across the exchanger.

A sprinkler system can be performed under the layer of thermal/humidity insulation. Based on a study [1], it was found that sprinkler pipes having a nominal diameter of ø 25 mm, perforated with ø 2 mm holes made at an angle of 90° at intervals of 10 cm are the cheapest and best for this purpose. The optimal distance between pipes is 0.5 m. The sprinkler system enables possible periodic disinfection and washing of the bed. It also facilitates intensification of heat and mass exchange processes in the accumulation filling, especially in the context of increasing the relative humidity of the air which leaves it. The research conducted by the Sanitary-Epidemiology Station in Wroclaw on an exchanger which has been working for many years without sprinkling did not show any microorganisms harmful to human health in the air discharged from the exchanger. On contrary – it was concluded that the number of particles from air pollution following the exchanger got reduced to half of the value contained in atmospheric air [2]. Thus, the exchanger is additionally a specific kind of filter. These results are also confirmed by publications concerning other exchangers of this type operating in Poland. The experiments [2] of hydrating of the bed during its operation show that it does not cause a significant decrease in the air temperature. It only, due to moisturising, significantly increases relative humidity to values near to saturation, i.e. φ = 100%. Additionally, during the course of the study, it was noted that similar parameters are obtained by humidifying only the inlet section of the filling [2]. This allows for possible savings when constructing systems where it is important for some operating periods to achieve higher relative air humidity at the outlet. In addition, what is important, hydraulics tests of the filling performed during sprinkling of the inlet section only, as well as of the entire filling, did not show increase in resistance of the airflow across the bed.

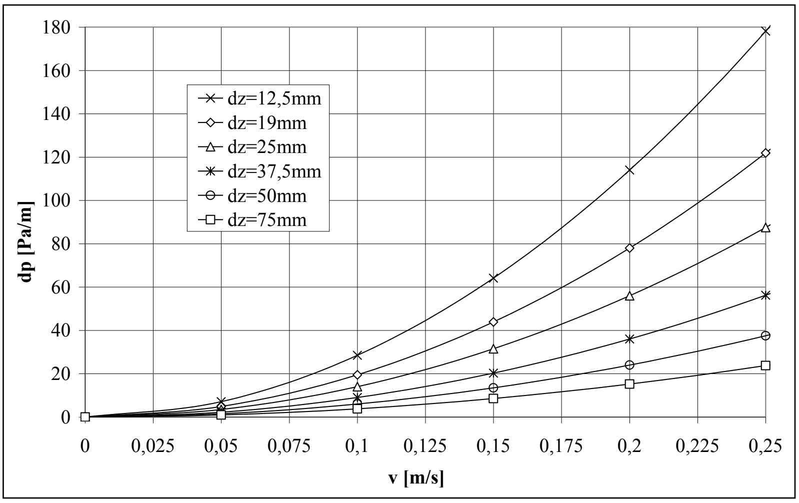

Fig. 2. Practical chart to determine the pressure loss in the bed according to [3].

Fig. 2 shows a practical, usable during designing, experimentally determined dependency between air flow velocity (v) and pressure loss (dp) of the accumulation bed for different hydraulic diameters used in BGWCiM.

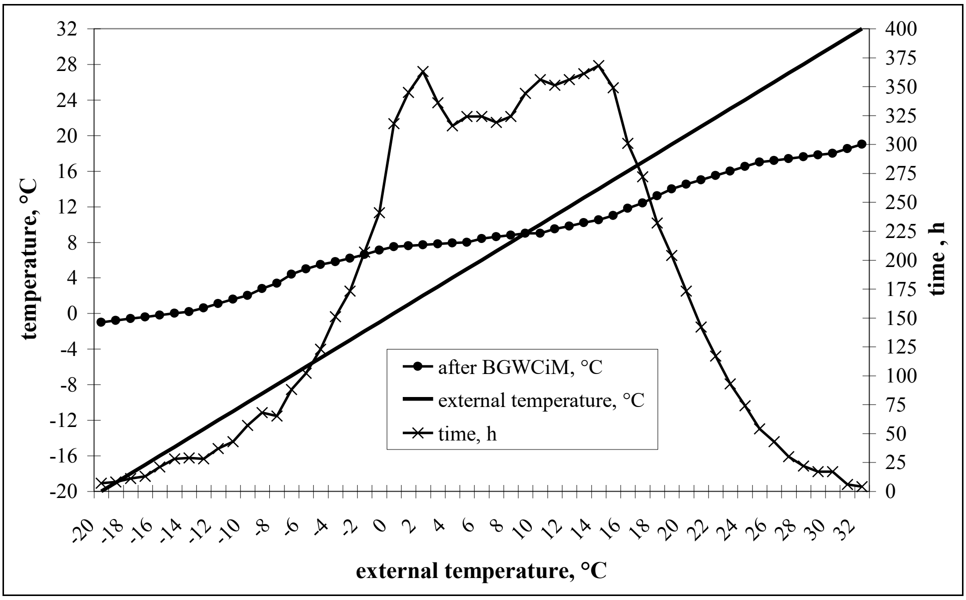

Fig. 3. Average air temperature values following the ground exchanger and a number of hours of occurrence of given outdoor temperatures during a year for A type of heat exchanger, 5 m length, 0.14 m/s air velocity, operated year-round continuously [2, 3].

In fig. 3 average values of air temperature after passing through BGWCiM and average times of occurrence of given outdoor temperature data for Wroclaw [2] were presented. They were indicated and statistically calculated on the basis of many years of measurements. This chart can be used in designing and provide the basis for performance of any analyses connected with the full-year operation of the device.

As a result of air contact with the ground in BGWCiM, the soil gets drained during periods of hot summer, moisturised in winter and cleansed. The above is achieved only by negligible energy inputs necessary to overcome the airflow resistance through the bed.

2 Conditioning rooms in the industry

2.1 Required air parameters

Each type of production, depending on the technology used, requires very specific microclimate conditions (table 1) to produce a given product of possibly the highest quality. What must not be overlooked is also the human aspect. In order to achieve high productivity, the best possible conditions must also be created in the work area. It often happens that the production requirements and the comfort conditions of the people differ. It is when the technology is more important. Ventilation in an industrial plant constitutes a service component rather than a core business. However, production would be impossible without the optimal conditions of the microclimate. An important issue for the ventilation system to be economically viable. Therefore, it must provide appropriate parameters for both the technological process and people, ensuring minimal investment and operating costs [4].

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Table 1. Recommended temperature and humidity ranges for various industrial processes [6].

No.	Industry	Plant type	Temperature	Relative humidity
-	-	-	°C	%
1	*2*	*3*	*4*	*5*
1	Libraries	Books warehouse	21–25	40–50
		Reading rooms	21–25	35–55
2	Breweries	Fermentation rooms	4–8	60–70
		Barrels of malt	10–15	80–85
3	Printing works	Paper warehousing	20–26	50–60
		Printing	22–26	45–60
		Multicolour printing	24–28	46–50
		Photographic printing	21–23	60
		All other works	21–23	50–60
4	Furs	Warehousing	5–10	50–60
		Drying	43	-
5	Museums	Paintings	18–24	40–55
6	Bakeries	Flour warehouse	15–25	50–80
		Yeast warehouse	0–5	60–75
		Dough making	23–25	50–60
		Sugar warehouse	25	35
7	Mushroom cultivation	Growth period	10–18	-
		Warehousing	0–2	80–85
8	Linoleum production	Oxidation of linseed oil	32–38	20–28
		Printing	26–28	30–50
9	Confectionery industry	Warehousing (dried fruit)	10–13	50
		Soft sweets	21–24	45
		Production of hard sweets	24–26	30–40
		Packing of hard sweets	24–28	40–45
		Chocolate production	15–18	50–55
		Chocolate wrapping	24–27	55–60
		Chocolate packing	18	55
		Chocolate warehousing	18–21	60–65
		Fruitcake and wafers production	18–20	50
10	Electrical engineering industry	General production	21	50–55
		Production of thermo- and, hygrostats	24	56–55
		Production with small tolerances	22	40–45
		Production of isolations	24	65–70
11	Pharmaceutical industry	Semi-products warehousing	21–27	30–40
		Manufacture of tablets	21–27	35–50
12	Photographic industry	Production of normal films	20–24	40–65
		Production of non-flammable films	15–20	45–50
		Treatment of films	20–24	40–60
		Darkroom	21–22	45–50
		Photographic studio	22–23	40–50
		Films warehousing	18–22	40–60
13	Rubber industry	Warehousing	16,24	40–50
		Manufacturing	31–33	-
		Vulcanisation	26,28	25–30
		Surgical materials	24–33	25–30
14	Paper industry	Machines	22–30	50–60
		Paper warehouses	20–24	50–60
15	Tobacco industry	Raw tobacco warehousing	21–23	50,65
		Tobacco preparation	22–26	75–85
		Tobacco warehousing	24–25	70–75
		Tobacco steeping	32	85–88
		Manufacture of cigarettes and cigars	21–24	55–65
		Packing	23	65

Table 1. continued…

No.	Industry	Plant type	Temperature	Relative humidity
-	-	-	°C	%
1	*2*	*3*	*4*	*5*
16	Textile industry	Bath	22–25	40–50
	- cotton	Carding machine	22,25	50–55
		Comber	22–25	45–55
		Textile stretching machine	22–25	50–55
		Roving frame	22–25	50–55
		Ring frame	22–25	40–45
		Spooling, spinning, trimming, pulling warp	22–25	60–70
	Textile industry	Preparation	18–20	80
	- flax fibres	Carding mill	20–25	50–65
		Spinning	24–27	65–75
		Weaving	27	65–70
	Textile industry	Preparation	27–29	60
	- wool	Carding mill	27–29	65–70
		Spinning	27–29	50–60
		Weaving	27–29	60–70
		Equipping	24	50–60
	Textile industry	Preparation	27	60–65
	- silk	Spinning	24–27	65–70
		Weaving	24–27	60–75
	Textile industry	Carding, spinning	21–25	65–75
	- rayon	Weaving	24–25	60–65
17	Match	Production	18–22	50
	industry	Warehousing	15	50
18	Mechanical	Offices, warehousing, general assembly	20–24	35–55
	plants	Precision assembly	22–24	40–50
19	Matches	Production	22–23	50
		Drying	21–24	60
		Warehousing	16–17	50
20	Leather	Drying	20–52	75
		Warehousing	10–18	40–60
21	Plastics	Thermosetting injection-moulded plastics	27	25–30
		Cellophane coated	24–27	45–65
22	Optical industry	Application	24	45
		Grinding	27	80
23	Ceramics	Treatment of refractory materials	43–66	50–90
		Storage of clay	16–27	35–63
		Decoration of ceramics	24–27	48
24	Electronics	Winding of reels	22	15
		Semiconductor assemblies	20	40–60
25	Electrical devices	Production and metrological tests	21	50–55
		Assembly and calibration of thermostats	24	50–55
		Assembly and calibration of hygrostats	24	50–55
26	Precision mechanics	Assemblies having strict dimension tolerances	22	40–45
		Assembly and tests of measuring devices	24	60–63
27	Distributor apparatus	Fuses and circuit breakers	23	50
	and switchers	Winding of power capacitors	23	50
		Paper insulation warehousing	23	50

2.2 Use of BGWCIM

In fig. 4 there are areas presented which show the nature of the variability of the outdoor air and the air following BGWCiM, recorded in the climatic zone of Poland.

Moreover, in this drawing the so-called climatic curve is indicated, which shows average outdoor air parameters of Poland's geographical area and typical parameters of thermal comfort.

When referring to the air parameters following BGWCiM to the air parameters required in production processes (room temperature and air conditioning temperature), it can be seen that the use of the exchanger for air preheating will not always be cost effective. During the cold season, except for processes requiring very low humidity in the room (dry rooms), preheating and humidification will be almost always beneficial. This differs in the case of the transition and warm periods, when too much humidification of the air in the ground heat exchanger, usually close to the saturation parameters, will cause the need to dry it, which will be associated with additional costs which can exceed the savings resulting from the temperature drop.

Beneficial effects of using BGWCiM should be expected in air treatment systems for air conditioning of rooms with relatively high temperature and high relative humidity (e.g. textile industry, tobacco industry, etc.).

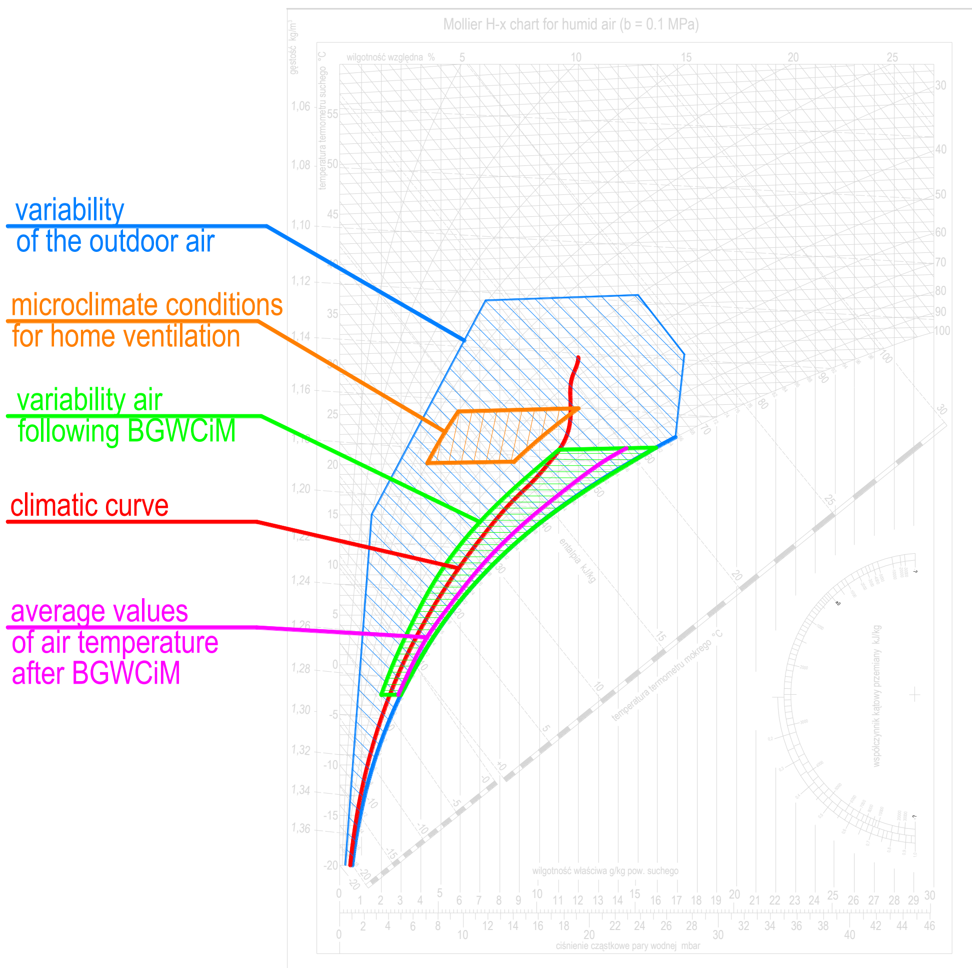

Fig. 4. Ranges of changes in air parameters.

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3 Conclusion

The decision to use BGWCiM to pre-prepare the air in the process of air conditioning of production rooms should be each time preceded by an in-depth analysis of the full-year operation of the system with a full assessment of possible effects. Restrictive requirements for microclimate parameters in many industries will not always be achievable with BGWCiM alone or with BGWCiM serving to pre-prepare the air. Wherever the analysis confirms the suitability of its use, savings of up to 30% per year of energy consumed can to be expected, compared to BGWCiM-free system while reducing power and size of other air treatment devices (e.g. heaters, radiators, heat sources, chillers, humidifiers, etc.) [2].

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