Innovative Ideas LLC

Test report
on the prototype of the apparatus
for indirect regenerative evaporative cooling

March 2021

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0.1 Introduction

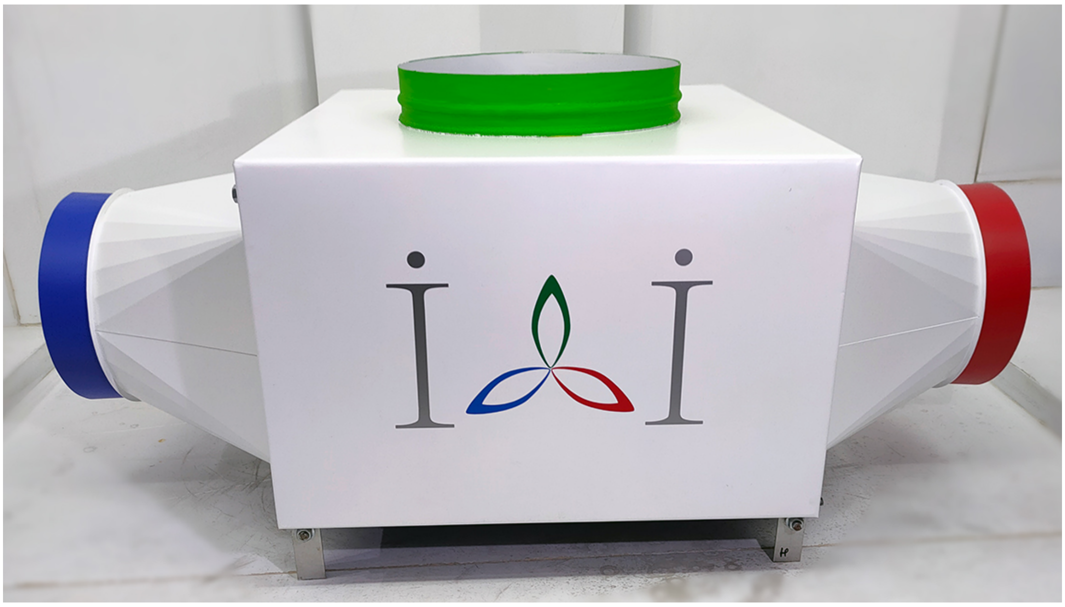


Figure 1: Prototype of the apparatus for indirect regenerative evaporative cooling by Innovative Ideas LLC

The principle of operation of the apparatus for indirect regenerative evaporative cooling is as follows: air from the environment is supplied by a fan into the apparatus, after which it is divided into two components: working flow passes through a system of dry channels (transfers heat to wet channels and is cooled at constant moisture content) and wet channels (air is heated and saturated with water vapor at a constant relative humidity RH). In turn, the second component of the input air flow is product (air that is cooled and supplied to the consumer), passing through the system of dry channels, gives off its heat to the wet channels, as a result of which it cools at a constant moisture content. The design feature of the device allows air to be cooled to the wet bulb temperature and even lower at certain parameters of the inlet air flow (approaching to the dew point as to the theoretical limit). The simplicity of the device design testifies to its reliability and economy.

Advantages of this device over vapor compression machines:

- 100% fresh, filtered, cold and comfortable air with no added humidity;
- The air supplied to the consumer is not dehumidified (which is observed during the operation of classic vapor compression units). As is known, excessively dry air leads to discomfort;
- Uses up to 90% less electricity compared to traditional air conditioners: only a ventilator, automatic equipment and a small pump work inside;
- Cooling capacity increases with temperature growth: the hotter the air enters to the unit, the higher the efficiency of the device. In a practical sense, this means that a strong increase in the inlet temperature does not lead to the same increase in the outlet temperature: the device still produces a temperature close to comfortable;
- No refrigerants containing CFCs that are harmful to the environment;
- Quiet.

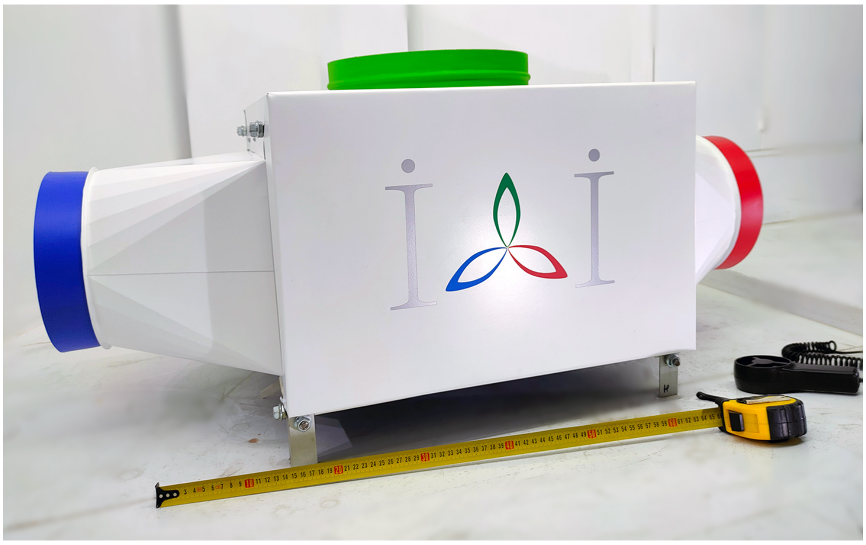
Disadvantages:

- Consumes water (water supply system is required);
- Limitation of the outlet temperature due to its direct dependence on the dew point temperature of inlet air. Below this temperature, it is impossible to cool the air only by means of this device. Therefore, the cooling performance of the device directly depends on the moisture content of the ambient air.

In the case if the latter drawback is critical, its effect can be reduced by application the device in combination with a conventional air conditioner: the device supplies clean and precooled air, and the vapor compressor air conditioner cools it down to the required temperature. At the same time, the energy consumption for the operation of the vapor compression refrigeration unit is noticeably reduced, which ultimately leads to significant cost savings.

Water consumption does not lead to the formation of mold and its ingress into the room, as it happens with conventional air conditioning: supplied to the room air has no contact with water; water constantly evaporates and is supplied to the device as needed without stagnation inside; a surfactant is mixed into water in small doses, and the water transporting material itself is bioinert.

The prototype shown in the photo consists of one heat and mass transfer core, designed to produce about $460\,m^3/h$ of cooled air and $340\,m^3/h$ $100\,\%$ - humid air with a consumption of $800\,m^3/h$ of outer air. The practical application of the tested prototype consists in the use of 3 to 6 such cores in one apparatus and the subsequent modular arrangement of these apparatuses together in the amount needed to cool the required volume of air.



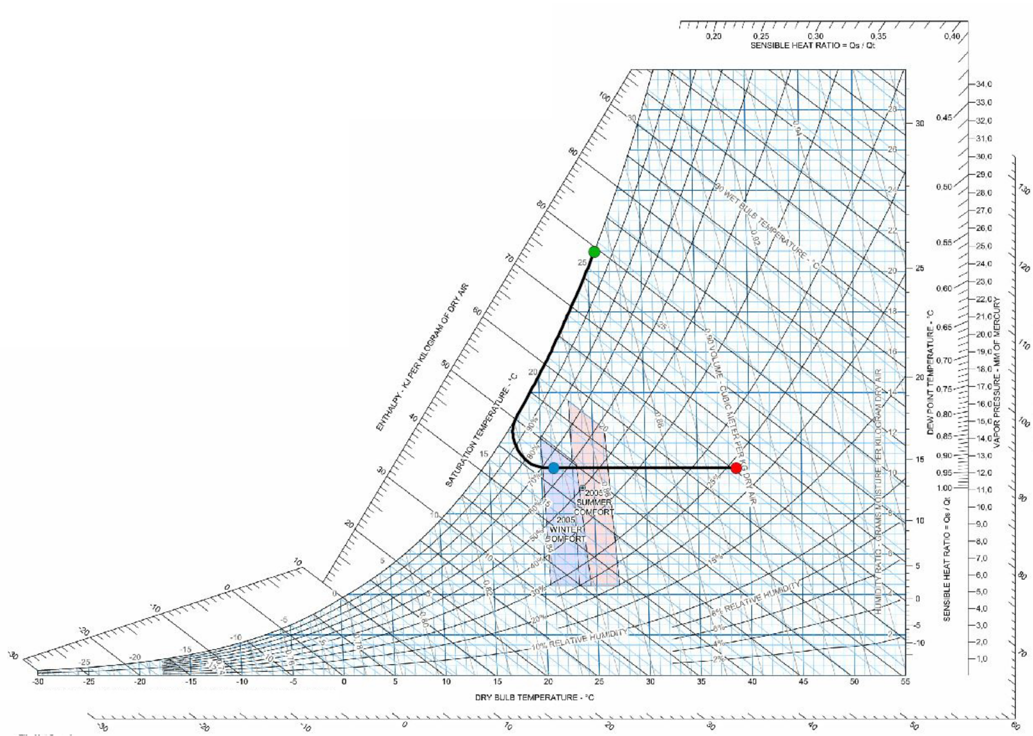


Figure 2: Cooling process on a psychrometric diagram of humid air for
$t_1 = 38.3°C$ $RH_1 = 24\%$ $t_2 = 20.4°C$

0.2 Test results

This section contains the results of testing the apparatus for indirect regenerative evaporative cooling (Table 1). The tests were carried out with maintaining a steady state at the input to the apparatus (temperature t_1, relative humidity RH_1 and air flow $V_1 = 800\, m^3/hour$), while measuring steady-state output parameters of the product (index 2 in the designation of the measured values) and working flows (index 3) of air*. During the tests, the electrical power N and water mass flow rate G_w, supplied to the system, were also recorded. Operating parameters were selected, including based on the analysis of statistical weather data for the target region (Sumy). In the figure 3, the dots highlighted in black denote the regime parameters with the most frequent repeatability for the region under consideration, as well as for hot regions where the effect of this apparatus will be maximum.

The obtained experimental data were used to analyze the efficiency of cooling process using a wet bulb E_{wb} and dew point temperature E_{dp} for each studied mode as a generally accepted method for evaluating the effectiveness of devices of this type.

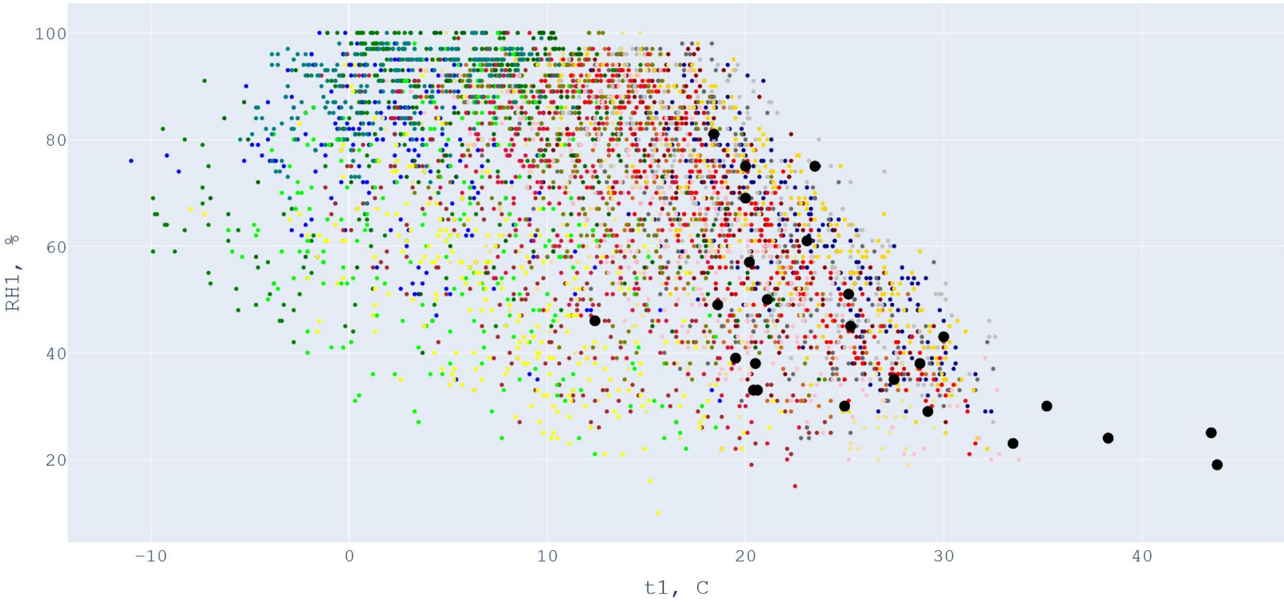


Figure 3: Scatter diagram of the distribution of temperature and relative humidity in Sumy city, spring-autumn 2019-2020, with a 3-hour interval

*These and other data are available in the test materials attached to the report

Table 1: Test results of heat and mass transfer core of the apparatus

№	t_1, C	$RH_1, \%$	t_2, C	t_{1dp}, C	t_{1wb}, C	$E_{dp}, \%$	$E_{wb}, \%$	N, W	$G_w, kg/h$
1	12.4	46	8.0	1.1	7.1	38.9	83.0	183	3.2
2	18.4	81	16.2	15.1	16.3	66.7	104.8	184	1.6
3	18.6	49	12.5	7.7	12.5	56.0	100.0	184	4
4	19.5	39	12.1	5.2	11.8	51.7	96.1	184	4.8
5	20.2	57	15.0	11.4	14.9	59.1	98.1	181	4
6	20.0	69	16.2	14.1	16.3	64.4	102.7	185	2.4
7	20.0	75	17.0	15.4	17.1	65.2	103.4	184	2.4
8	20.4	33	12.3	3.6	11.6	48.2	92.0	181	4.8
9	20.5	38	13.2	5.7	12.4	49.3	90.1	180	4.8
10	21.1	50	14.8	10.3	14.7	58.3	98.4	185	4
11	23.1	61	18.0	15.2	18.0	64.6	100.0	185	3.2
12	23.5	75	20.4	18.8	20.3	66.0	96.9	184	2.4
13	25.0	30	14.7	6.2	14.4	54.8	97.2	184	4.8
14	25.2	51	18.2	14.4	18.2	64.8	100.0	184	4.8
15	25.3	45	17.5	12.5	17.3	60.9	97.5	183	4.8
16	28.8	38	18.6	13.1	18.7	65.0	101.0	186	6.4
17	29.2	29	16.6	9.4	17.2	63.6	105.0	184	4.8
18	30.0	43	20.6	16.1	20.7	67.6	101.1	185	5.6
19	33.5	23	18.4	9.5	18.7	62.9	102.0	184	9.6
20	35.2	30	20.4	15.0	21.7	73.3	109.6	183	8.8
21	38.3	24	20.4	14.2	22.1	74.3	110.5	184	9.6
22	43.5	25	23.8	19.2	26.0	81.1	112.6	185	10.4
23	43.8	19	21.4	15.1	24.1	78.0	113.7	186	10.4

For each mode, the volumetric flow rate of the product stream was maintained about $V_2 = 440\, m^3/h$.

0.3 Analysis

As a result of the conducted tests, a surface was built on the basis of experimental points (black points lying on the surface). Using this surface, it is possible to estimate the output temperature t_2 for other (intermediate / close) input parameters t_1 and RH_1, which are not presented in the table 1. To separate the area of reliable data, obtained using this surface, an auxiliary saturation surface (2) was constructed, corresponding to the theoretical limit value of the outlet product temperature (dew point). In this case, the confidence zone of the response surface (1) is its part located above the saturation surface.

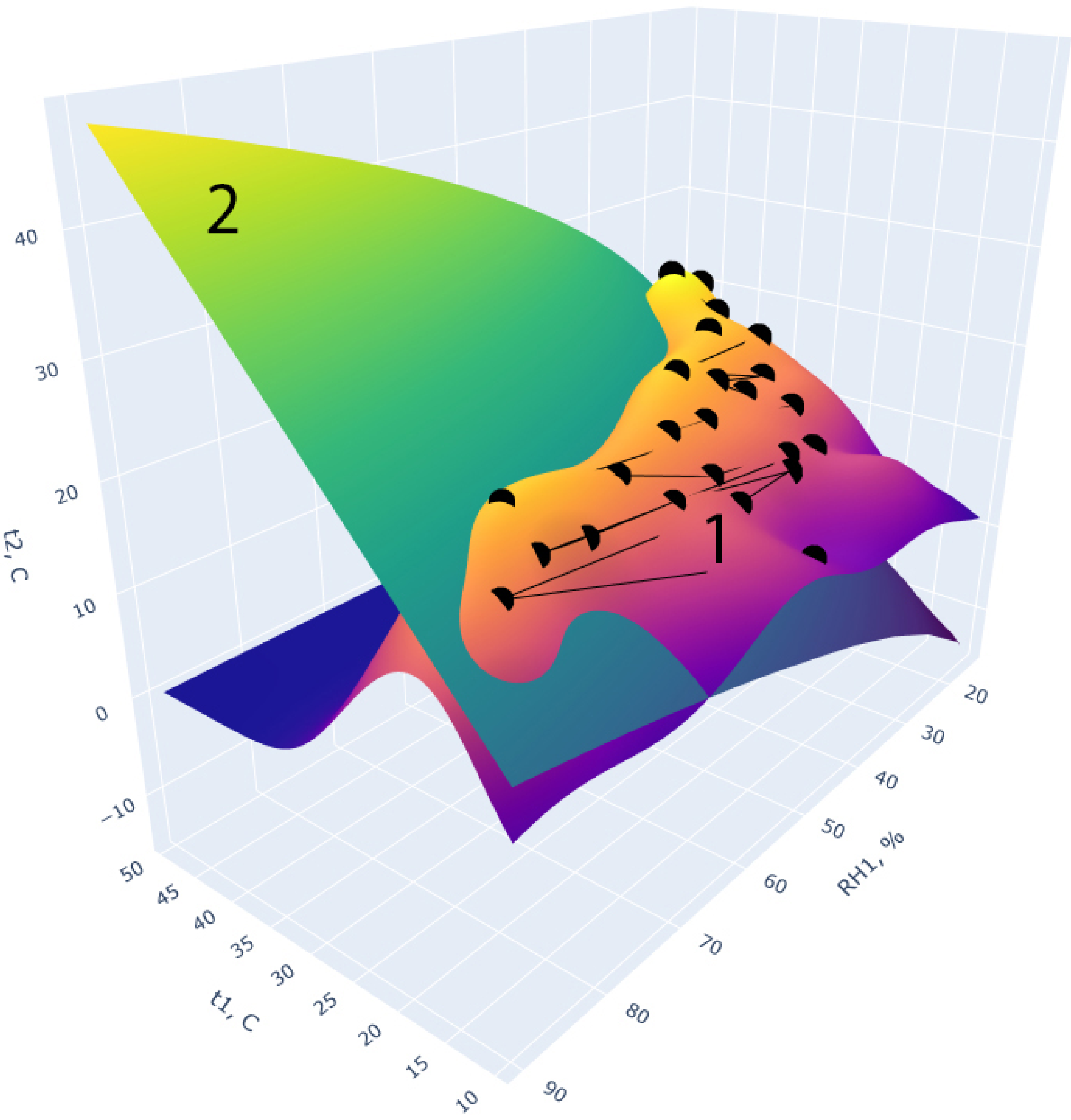


Figure 4: Output temperature surface t_2 (1) depending on the input parameters t_1 and RH_1

0.4 Comparison with analogues

Today, in the global evaporative cooling market, analogues of this device are Seeley International products under the Coolerado brand, such as m30 (3 cores), m50 (5 cores), c60 (6 cores), etc. To evaluate the efficiency of such devices, Seeley International uses the environmental parameters $t_1 = 38°C$ and $RH_1 = 20.8\%$ as the nominal mode. Therefore, it is logical to compare the cooling capacity (Q) of the developed prototype with the cooling capacity of similar products from Seeley International (the green dot in Fig. 4 is shown for the m50 apparatus per 1 core with the refrigerating capacity $Q = 2.36\,kW$).

The figure shows that the developed prototype has a higher cooling capacity by $0.34\,kW$, which is an increase of more than 14%.

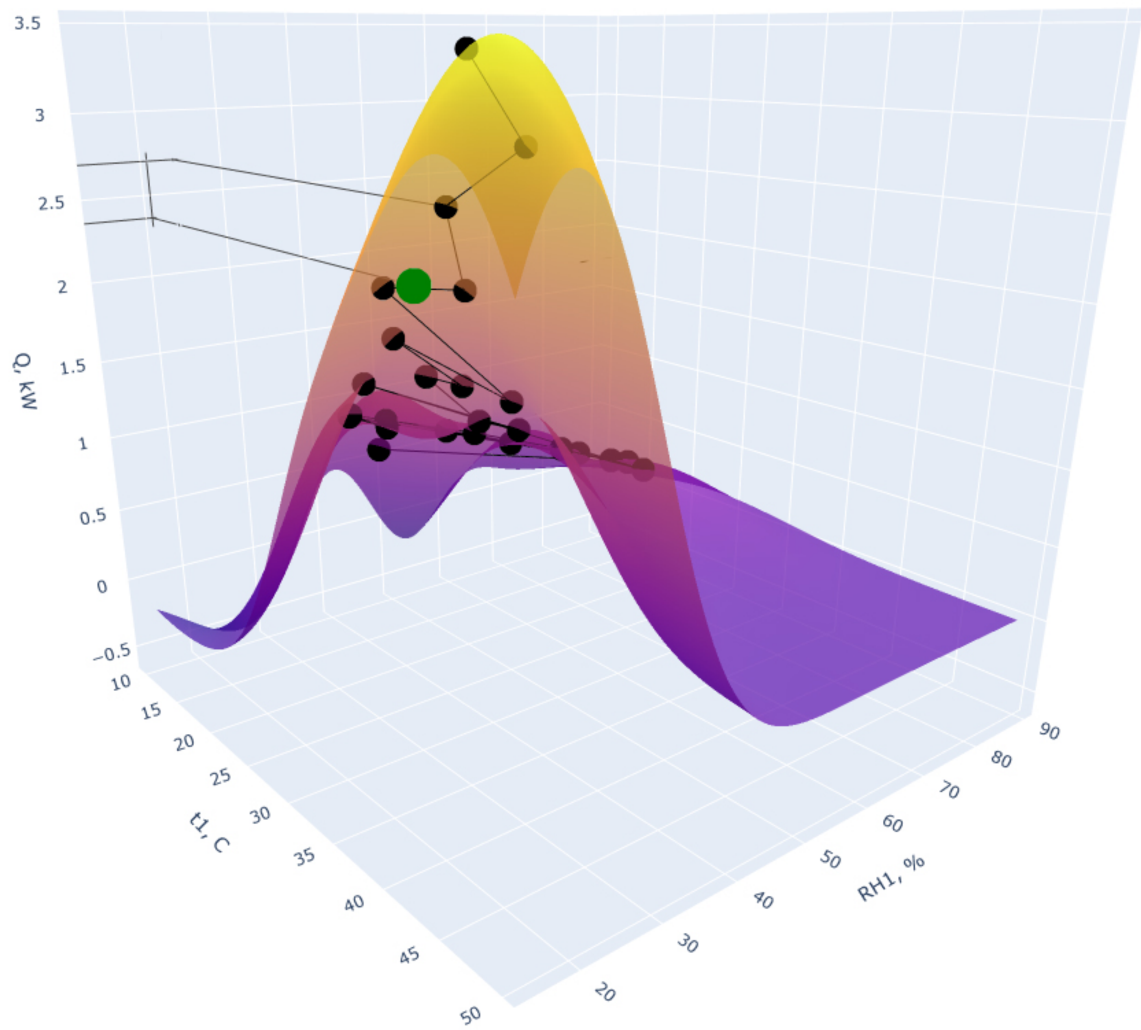


Figure 5: Dependence of the prototype cooling capacity on the input parameters t_1 and RH_1

0.5 Cost-effectiveness analysis

The analysis of the economic efficiency of the apparatus was carried out taking into account the real operating costs for the period spring-autumn 2019-2020 with a 3-hour interval for Sumy region. The temperature of the cooled air supplied to the consumer was taken as $16°C$, the price per kW/h of electricity 4.11 UAH, the price per m^3 of water (with drainage) 27.12 UAH.

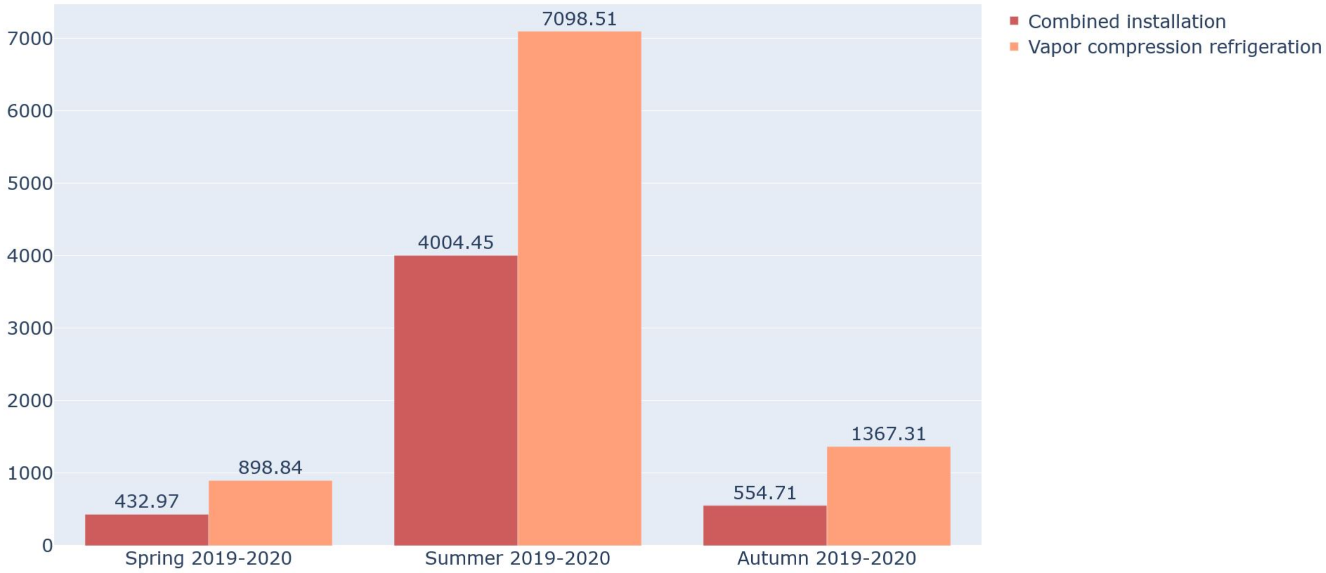


Figure 6: Operating costs for the volumetric flow rate $440\, m3/hour$ of the supplied air to the consumer for the period spring-autumn 2019-2020 (UAH)

During the analysis, two schemes of air supply system to the consumer were considered and compared:

1) Vapor compression refrigeration unit (VCRU) in combination with an indirect regenerative evaporative cooling unit (IRECU);

2) Vapor compression refrigeration unit only.

For both schemes, environmental parameters were taken into account in such way, that if the ambient temperature is below $16°C$, then the refrigeration units are not turned on, therefore, there are no electricity costs.

The operating mode of the 1st scheme is arranged in such way that when the ambient temperature is more than $16°C$ and $t_2 \leq 16°C$, the VCRU also does not turn on. If the ambient temperature is more than $16°C$ and $t_2 > 16°C$, then the VCRU is switched on for additional cooling of the air supplied to the consumer to a temperature of $16°C$. Thus, in the first scheme, the VCRU is switched on only in cases when it is necessary to compensate the lack of cooling capacity of the prototype core, which brings a noticeable energy saving.

For the 2nd scheme, the VCRU always provides cooling capacity caused by existing temperature difference between the environment and $16°C$, what, as a rule, leads to increased energy consumption.

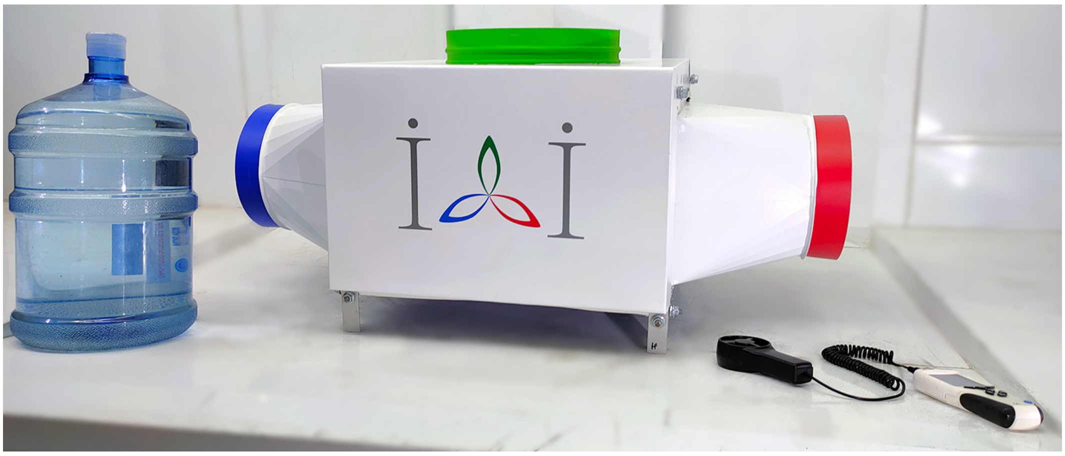
As one can see from Figure 5, usage of a combined installation gives an almost two-fold reduction of operating costs. It should be noted that the tests of the prototype core were carried out in conditions as close as possible to real ones. At the same time, analyzing the economic effect, the inlet air parameters to the prototype core were taken from statistical data of the environment that inherently skewed against the prototype putting it into the worst working conditions, since in reality such units are installed on the roofs of consumer facilities, where the installations have to compensate significantly higher heat gains than reflected in these data due to solar radiation. In addition, assessing the energy consumption of the VCRU, the coefficient of performance $COP = 3$ were taken, that does not correspond to the real average COP values for refrigeration machine which operates at high ambient temperatures (for such conditions, COP has significantly lower values). This was done in order to simulate the worst-case scenario for the IRECU prototype. Thus, the operational cost benefit is expected to be significantly greater in real-world operation.

0.6 Conclusions

It has been experimentally proven that the IRECU prototype by Innovative Ideas LLC is more efficient than its counterparts (Seeley International products under the Coolerado brand).

The advantages over classical vapor compression units are shown, including the analytically proven benefits of their combined use.

At the same time, there are reserves for increasing the capacity and efficiency of the heat and mass exchange core due to the use of new materials, layouts, desiccants and other measures. Moreover, based on the tested core of the IRECU prototype, it is possible to develop new products intended for variety of applications: water from air, heating, humidification and heat recovery systems.



Attachments

Prototype test materials are available upon request:

- List and specifications of used measuring instruments;
- Data files recorded during the experiment, graphs built on this data;
- Interactive 3D diagrams for product outlet temperature and unit cooling capacity depending on input parameters t_1 and RH_1;
- A file of statistical data on the distribution of temperature and relative humidity in Sumy city, spring-autumn 2019-2020, with a 3-hour interval.