Investigation of the Operation of Inverter Units for the Possibility of Working in the Cooling Mode at Low Outdoor Temperatures

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Abstract. The possibility of avoiding problems associated with low outdoor air temperatures at the design stage of the air conditioning system of a responsible object is considered. A study was conducted in laboratory conditions to determine the operability of inverter split systems at an ambient (outdoor) air temperature of "minus" 30 °C. As a result of field tests in laboratory conditions, the possibility of operating inverter split systems in cooling mode at an ambient temperature of "minus" 30 °C is presented.

1. Introduction

The functioning of split air conditioning systems has a pronounced dependence on the parameters of the outdoor air and the microclimate of the serviced premises [1; 2]. This dependence has a significant impact on the energy efficiency of the air conditioning system [3; 4]. When the outside air temperature increases, the pressure on the compressor discharge side increases, and when it decreases, the boiling point of the refrigerant decreases. Thus, the temperature range of the split air conditioner is limited by the boiling point of the refrigerant equal to 0 °C (due to the absence of freezing of the evaporative heat exchanger), and the condensation temperature of the refrigerant exceeding the outdoor temperature and equal to 50-60 °C [5].

2. Relevance

When the outdoor air temperature changes, the processes occurring in the main elements of the steam compression refrigerating machine (compressor, evaporator, condenser, throttle) undergo changes associated with the differentiation of the condensation pressure in the heat exchanger of the outdoor unit of the split air conditioning system. In order to establish the influence of the external temperature on the operation of the steam compression refrigerating machine, experimental studies were carried out, during which the temperature was measured at characteristic points of the refrigeration cycle: after the evaporator, after the compressor, after the condenser, after the throttle (capillary tube), as well as the pressure of the refrigerant before and after the compressor. The experimental data were averaged at an outdoor temperature of "minus"30 °C.

The experiment was conducted from May to July 2021 on installations built on the basis of wall-mounted inverter-type air conditioners: Royal Clima VELA Inverter RCI-VNR37HN; Royal Clima TRIUMPH Inverter RCI-T30HN; Hisense SMART DC Inverter AS-11UR4SYDDB15G. [5].
At the design stage of the air conditioning system of high-responsibility facilities (server rooms, command posts, TV studios, rooms with a large number of people and equipment for various purposes), all problems associated with low outdoor temperatures can be avoided.

The experience of designing and operating such systems is large enough to ensure that they can be used for year-round air conditioning in any harsh climate. Moreover, all the leading manufacturers of air conditioning systems have the necessary equipment and engineering support in their production programs. However, air conditioning systems with an air-cooled condenser are much simpler, cheaper and more economical to operate. Unfortunately, their year-round use in areas with a continental climate, severe winters is hampered by a number of sometimes unsolvable problems.

The equipment in the considered split systems from different manufacturers has been modified for the possibility of use in air conditioning systems in the cooling mode during the cold period of the year ("minus"30 °C).

3. Equipment modification

All split systems were previously modified with variators (condensation pressure regulators), compressor crankcase heaters, and capillary tube heaters. The split systems Hisense Smart and RC Vela were also previously modified by the so-called "decoys" to change the readings of pipe temperature sensors, air temperature sensors and discharge temperature sensors in outdoor units so that the outdoor units receive data on the minimum temperature not lower than "minus"15 °C.

The RC Triumph split system was modified by the so-called "decoys" for air, pipe and discharge temperature sensors after the start of the tests (to check the operability).

4. Testing conditions

The outdoor units are located in a heat-insulated cooled room (refrigerator) with a temperature of "minus"26..."minus"30 °C.

The indoor units are located in an adjacent room at an internal temperature ("plus" 20 ... "plus" 24 °C). Heating devices with a total heat output of 4 kW (2.5 kW oil radiator and 1.5 kW fan heater) are placed next to the internal units of split systems to compensate for the decrease in temperature in the room.

The length of the tracks from the outdoor units to the indoor units of all split systems was 15 m.

The height difference of the tracks is artificially created for the split systems RC Vela and Hisense Smart and is 2 meters (the track rises by 2 meters and then falls by 2 meters). The height difference of the track of the RC Triumph split system is 2 meters (the track rises by 2 meters and is connected to the indoor unit).

The freon tracks of the RC Vela and Hisense Smart air conditioners are insulated along the entire length, the track of the RC Triumph air conditioner is insulated by 7 meters.

On the internal units of split systems, the minimum temperature is set ("plus" +16 ... "plus" 17 °C), the fan speed is "high". The systems operate in cooling mode.

5. Measured and monitored parameters

- Air temperature at the entrance to the internal unit of the split system;
- The air temperature at the outlet of the internal unit of the split system;
- Temperature difference at the inlet and outlet of the internal unit of the split system;
- Instantaneous current consumption of the entire system;
- Refrigerant condensation pressure;
- Air temperature in the cooled room;
- System operability (presence of errors on the split system display);
- The condition of the heat exchanger of the indoor unit (the presence/absence of icing and its degree) [7; 8].
6. Preliminary testing of the performance of split systems

Preliminary testing of the split system performance lasted 2 hours (from 9:00 to 11:00) on 18.07.2021.

The results of preliminary testing – all split systems work without errors and provide a temperature difference at the input and output of indoor units from 5 to 10 °C.

7. Basic performance testing of split systems

The main performance testing of split systems lasted 5 hours (from 11:00 to 16:00) on 18.07.2021.

The following changes were made during the testing process:

- 13:16-disconnection and subsequent activation after 5 minutes of the Royal Clima TRIUMPH Inverter RCI-T30HN unit for updating the outdoor air temperature sensor with a "decoy";
- 14:00-disconnection and subsequent activation after 5 minutes of the Royal Clima TRIUMPH Inverter RCI-T30HN unit for updating the pipe temperature sensor and the "decoy" discharge temperature sensor;
- 15:20-installation of wind protection on all outdoor units of air conditioners (blocking the rear surface of the heat exchanger).

The results of monitoring the monitored parameters are shown in Table 1.

| Time   | T_{Entry}, °C | T_{Exit}, °C | Differ, °C | Current, A | Condensat\on pressure, Bar | T in the camera, °C | Problems/observed effects |
|--------|---------------|--------------|------------|------------|--------------------------|---------------------|--------------------------|
| 9:32   | 19,8          | 14,4         | 5,4        | 0.96       | /                        | /                   | -26                      |
| 11:00  | 23            | 17,5         | 5,5        | /          | /                        | /                   |                          |
| 11:10  | 23,5          | 17,8         | 5,7        | /          | /                        | /                   |                          |
| 11:42  | 23            | 18,2         | 4,8        | 0.85       | /                        | /                   |                          |
| 11:53  | 23,5          | 18,5         | 5          | 0.85       | /                        | -28,2               |                          |
| 12:04  | 20,8          | 14,2         | 6,6        | 0.9        | /                        | -26                 |                          |
| 12:12  | /             | /            | /          | 0.3        | /                        | -26                 |                          |
| 12:32  | 22,1          | 16,8         | 5,3        | 0.93       | /                        | -27,8               |                          |
| 12:57  | 21,8          | 18           | 3,8        | 0.85       | /                        | -29,9               |                          |
| 13:11  | 23            | 19,5         | 3,5        | 0.82       | /                        | -29,6               |                          |
| 14:41  | 23,7          | 16           | 7,7        | 1,05       | /                        | -29,3               |                          |
| Time  | Temp 1 | Temp 2 | Temp 3 | Temp 4 | Pressure | Action |
|-------|--------|--------|--------|--------|----------|--------|
| 15:00 | 23.4   | 18     | 5.4    | 0.95   | /        | -31    |
| 15:58 | 22     | 14     | 8      | 1.87   | /        | -27.3  |

Hisense SMART DC Inverter AS-11UR4SYDB15G

| Time  | Temp 1 | Temp 2 | Temp 3 | Temp 4 | Pressure | Action |
|-------|--------|--------|--------|--------|----------|--------|
| 10:06 | 19.5   | 11.8   | 7.7    | 1.48   | /        | -26    |
| 10:46 | 22.9   | 13.1   | 9.8    | 1      | 5-6 бар | -27.5  |

| Time  | Temp 1 | Temp 2 | Temp 3 | Temp 4 | Pressure | Action |
|-------|--------|--------|--------|--------|----------|--------|
| 10:51 | 23     | 15.2   | 7.8    | 1      | /        | -28.5  |
| 11:00 | 22     | 13.8   | 8.2    | /      | /        | -26    |
| 12:04 | 20.3   | 15     | 5.3    | 0.35   | /        | -26    |
| 12:19 | 20.4   | 15.4   | 5      | 1.25   | /        | -28.5  |
| 12:59 | 22.7   | 18.4   | 4.3    | 0.25   | /        | -29.9  |
| 13:13 | 23     | 19.5   | 3.5    | 0.28   | /        | -29.6  |
| 14:02 | 26.5   | 22.2   | 4.3    | 0.39   | /        | -31.1  |
| 15:00 | 23     | 19.1   | 3.9    | 1.1    | /        | -31    |
| 15:59 | 24     | 10.2   | 13.8   | 2.6    | /        | -27.3  |

Royal Clima VELA Inverter RCI-VNR37HN

| Time  | Temp 1 | Temp 2 | Temp 3 | Temp 4 | Pressure | Action |
|-------|--------|--------|--------|--------|----------|--------|
| 10:10 | 18     | 13.1   | 4.9    | 1.78   | /        | -28    |
| 11:00 | 21.5   | 8      | 13.5   | 1.5    | /        | -26    |
| 11:44 | 21.5   | 11.7   | 9.8    | 0.57   | /        | -29.5  |
| 12:32 | 19.4   | 10.8   | 8.6    | 0.19   | /        | -27.8  |
| 12:48 | 20.3   | 10.8   | 9.5    | 0.5    | /        | -26.8  |
| 13:00 | 21     | 9      | 12     | 0.63   | /        | -29.9  |
8. Monitoring the state of split systems

Work at -26 ... -30 °C and a strong wind load (wind 10-15 m/s) from 11:00 to 15:20, and subsequent work at a limited wind load from 15:20 to 16:00.

The RC Vela RCI-VNR37HN inverter split system works almost continuously (there were no exact signs of compressor shutdown). There is a gradual increase of frost on the front upper part of the heat exchanger of the indoor unit, followed by the transformation of this layer of frost into a layer of ice 2-3 mm. The upper part of the heat exchanger eventually becomes completely blocked for the passage of air. A part (2-4 cm) of the lower section of the heat exchanger is periodically overgrown with a thin layer of frost (up to 1 mm thick), followed by thawing. The air flow from the indoor unit has significantly decreased compared to the beginning of testing.

The temperature delta on the internal unit of the air conditioner is maintained almost stably throughout the entire experiment in the range of 7-12 °C (only 1 measurement falls out of this range).

After installing the wind protection (15:20), the internal unit of the split system completely thawed out in about 10 minutes, and the split system continued to work with an increased current consumption, keeping the temperature delta within 7-12 °C. The condensation pressure at this time changed from 5-7 bar (before installing the wind shield) to 17-25 bar (after installing the wind shield).

![RCI-VNR37HN](image)

**Figure 1.** Observations of the state of the RC Vela RCI-VNR37HN split system.

The Hisense SMART DC AS-11UR4SYDDB15G inverter split system works almost continuously (only a single shutdown of the compressor and a drop in delta T on the heat exchanger of the indoor unit at 14:15 was accurately recorded), but about half an hour after the start of the experiment, it goes...
to the minimum possible compressor speed. There is a gradual increase in frost on the front upper part of the heat exchanger of the indoor unit from the minimum (0-1mm) to the large (7-8mm). The upper front part of the heat exchanger of the indoor unit eventually becomes completely blocked for the passage of air. A part (2-4 cm) of the lower section of the heat exchanger is periodically overgrown with a thin layer of frost (up to 1 mm thick), followed by thawing. The air flow from the air conditioner has significantly weakened compared to the beginning of testing. The air flow from the indoor unit has decreased relative to the start of testing.

As can be seen from the graph, a satisfactory temperature delta is observed only at the beginning of the experiment and for a short time in the middle of the experiment, the rest of the time the temperature delta on the indoor unit of the air conditioner is below the permissible 7 °C.

After installing the wind protection (15: 20), the indoor unit of the air conditioner completely thawed in 10 minutes, and the split system continued to work with an increased current consumption, and the temperature delta on the indoor unit returned to the permissible range of 7-12 °C, and even exceeded it, amounting to almost 14 °C. The condensation pressure at this time changed from 5-7 bar (before installing the wind shield) to 17-25 bar (after installing the wind shield).

**Figure 2.** Observations of the state of the Hisense SMART DC AS-11UR4SYDB15G split system.

The Royal Clima TRIUMPH Inverter RCI-T30HN inverter split system operates in cycles of 35-40 minutes with a stop for 3-5 minutes and a subsequent restart. There is a slight (less than 1 mm) freezing of the heat exchanger of the indoor unit, the upper part, from 2/3 to 3/4 of the surface of the upper part. During periodic stops of the unit, this freezing is almost completely eliminated.

The temperature delta of this split system is below the permissible values (7-12 °C) for almost the entire duration of the experiment and passes into the permissible area only at the very end of it (after the introduction of deceptions of all sensors and the installation of wind protection). Despite the unsatisfactory temperature difference, this split system does not show serious freezing of the heat exchanger of the indoor unit and is able to work at low ambient temperatures for a long time. However, the condensation pressure of this system is in the range of 5-8 bar even after the installation of wind protection.
9. Conclusions

1. Operation of inverter split systems for cooling at ambient temperatures of “minus” 30 °C is possible only with the condition of providing wind protection (or with the condition of limiting permissible wind loads at a level of no more than 3 m/s at “minus” 30 °C), which, most likely, will have to be mechanically removed for the summer season. In the absence of wind protection, the RC Vela and Hisense Smart split systems show a constant and increasing freezing of the heat exchanger over time, which will eventually lead to a complete cessation of air exchange and turn off the air conditioner due to an accident or even failure. The RC Triumph split system works even if there is no wind protection (with a wind load of about 10-15 m/s), but it provides a minimal (most likely insufficient) temperature drop on the indoor unit.

2. In addition to installing the usual low-temperature kit (compressor crankcase heaters, capillary tube and drainage), additional installation of “decoys” on the temperature sensors for condensation, discharge and outdoor air of the outdoor unit will be required.

10. References

[1] Novoseltsev A, Glukhov S D, Stein A S, Mikhushkin V N 2013 Possibilities of modern air conditioning systems Engineering Journal: Science and Innovation 1 pp 75-83

[2] Stepanov V S et al Justification of the choice of the method of heat and humidity treatment of air in ventilation and air conditioning systems Bulletin of IrSTU 5(52) pp 90-94

[3] Baimachev E E, Sharova O V 2014 Determining the efficiency of a split air conditioning system with a steam compression refrigerating machine Bulletin of VSGUTU 2 pp 21-27

[4] Stepanov V S 2009 Methods for assessing the thermodynamic efficiency of microclimate maintenance systems Izvestiya vuzov. Construction 10 pp 46-54

[5] Posokhin V N, Ziganshin A M, Batalova A V 2012 On determining the coefficients of local resistances of disturbing elements of pipeline systems Izvestiya vuzov. Construction 9 pp 108-112

[6] Sargsyan S V 2015 Investigation of the ways to organize the air exchange and air diffusion systems on physical models in the laboratory conditions Scientific review 16 pp 68-71

[7] Sargsyan S V 2015 Methods of laboratory testing of the procedures of the air exchange organization on physical models Scientific review 16 pp 76-79