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Heat Recovery Variable Refrigerant Volume System Installation and Experiences from its Summer Operation

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Abstract

Variable refrigerant volume (VRV) systems operate on the principle of a cooling machine. They extract heat from one side and return it on the other, enabling them to function as a source of heat for both heating and hot water preparation, as well as a source of cold for cooling within a single building. These systems efficiently remove unnecessary excess heat outside and only introduce the required amount of heat from the outside into the building. With an appropriate configuration and setting, a VRV system can transfer heat in both directions within one system, eliminating the requirement for waste heat to be removed without use in the building. Instead, it is transferred to the desired locations where it is needed. This principle necessitates the adjustment of not only the refrigerant temperature but also its flow rate. Consequently, the VRV system can fulfil tasks that are otherwise handled by several individual systems in a building.

A heat recovery VRV system was installed in a small retail store to extract waste heat generated by baking ovens during the baking process. This report provides a brief summary of electricity and energy consumption measurements taken during the summer period for cooling purposes. Sequential logic is observed and coherence is ensured, with active voice predominating for clearer and more direct communication. The parameters of interest include cooling setpoints, cooling outside of working hours, and capacity assessment.

Keywords

heat recovery system, variable refrigerant volume, experimental measurement

1 Introduction

The process of baking pastry (Fig. 1) requires twice as much energy, both during the baking process and afterwards to maintain the desired temperature and reduce excess humidity. Normally, an air conditioning unit is used to regulate the temperature and moisture levels.

However, a heat recovery system with VRV technology has been chosen instead. This system utilizes the energy that would otherwise have been wasted from the cooling process for heating [1–3].

During testing in the summer period, we focused on the units' temperature setpoints, working hours outside, cooling and capacity assessments. The installation comprises 2 double outdoor units and 4 indoor units utilised in a sales area, 2 units used in a baking zone and 1 unit used in a chancellery. The total energy consumption of the installation throughout the 76 day testing period is around 4,151 kWh (Table 1, Fig. 2).

Fig. 1 Bakery in a small retail space (authors' archive)

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Table 1 Overview of individual energy consumption

Energy consumption (kWh)				
Cooling	Heating	Heat recovery	Non-specified consumption	Total consumption
4,139	3	4	5	4,151
99.712%	0.072%	0.096%	0.120%	100%

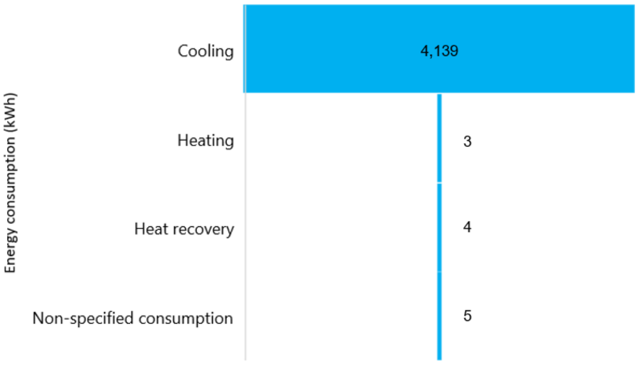

Fig. 2 Graph of individual energy consumption for an installation

The results obtained from experimental measurements or calculations were based on the following input data:

- installation location: Slovakia (420 m above sea level),
- calculated winter air temperature: −15 °C,
- calculated summer air temperature: +35 °C,
- enthalpy: 60 kJ/kg$_{da}$.

The following aspects included in this article become subject of interest.

2 Cooling during non-working hours

For comfortable applications, cooling outside working hours is generally unnecessary. The equipment can be turned off, or at least the set point can be raised. Consumption was nearly similar compared to working and non-working days (Fig. 3). A slight decrease can be explained by customers staying at home on Sundays rather than shopping.

This suggests that during these days, the bakery units operate less in cooling mode due to reduced baking. Based on the hourly energy consumption profile during working days, it seems that only few pieces of equipment operate outside of business hours, resulting in the consumption of around 13% of energy during non-opening hours.

Fresh pastry preparation commences at approximately 5^{30} a.m. by the staff. The baking process can be identified by the peak of the blue bar that occurs at 5^{00}–7^{00} a.m.

A retail facility requires a stable temperature to maintain the quality of stored products. Based on the hourly energy consumption profile during working days, it seems that only a few pieces of equipment operate outside of working hours. The following graph (Fig. 4) shows the hourly energy consumption, which can be used to assess the effectiveness of schedules and identify opportunities for energy conservation.

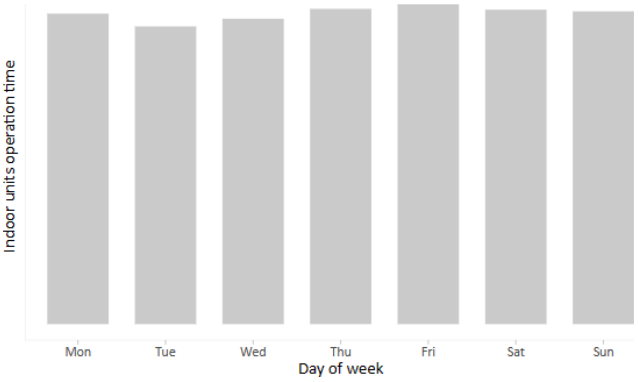

Fig. 3 Overview of weekly energy usage (proportional graph)

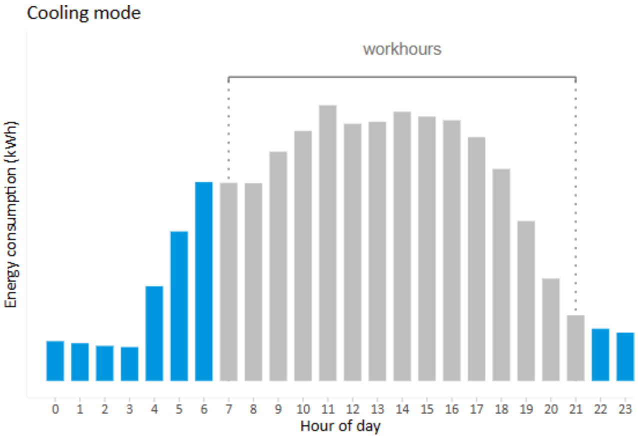

Fig. 4 Energy consumption on the busiest working days

During non-working hours in a cooling mode, it is usually possible to switch off the air conditioning equipment. As such, energy consumption should be minimized. It is recommended that energy consumption is kept low during non-working hours [4–6].

In heating mode, the equipment should be left to run continuously. If equipment failure occurs, energy consumption during night time should be reduced. Peaks in consumption noticeable at the beginning of business hours could signal a baking process, while those after 9^{00} p.m. suggest heat accumulation during the night.

3 Cooling temperature setpoints

The choice of setpoint considerably impacts energy consumption. Incidentally, increasing the indoor temperature by 1 °C typically has a 10% decrease on energy consumption. In relation to operating time, the median setpoint for indoor units was recorded at 23 °C [7]. This value is somewhat low, and assigning whole consumption to setpoints under 24 °C reveals that the highest energy peak occurred at 23 °C. Identifying the highest acceptable setpoints and scheduling units to adjust the temperature several times a day to the optimum value could be beneficial.

Another option is to limit the range of setpoints. During cooling mode, 99% of the total energy consumption occurred at setpoints below 24 °C. The highest energy consumption was at the setpoint of 23 °C, which is necessary to preserve the stored goods. The graphs in Fig. 5 show the operating time and energy usage at designated set points. The bars illustrate the contribution of each set point to the total energy consumption. These profiles help assess whether the set points are too low in cooling mode or too high in heating mode.

4 Capacity and building load assessment

If the outdoor unit only provides hourly averages of cooling and heating capacity, the assessment will be limited. However, if the outdoor unit provides representative values of cooling and heating capacity, detailed tables will display capacity gaps against the nominal capacities. Systems with larger gaps should be suitable for downsizing [8–10]. In the case of existing systems, downsizing could be achieved by adjusting target evaporating and condensing temperatures.

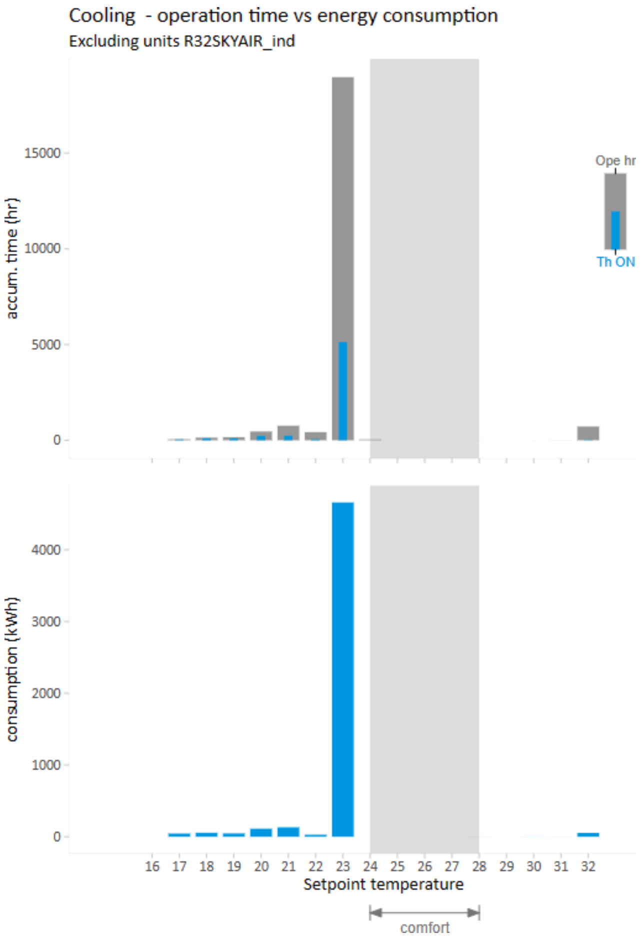

Fig. 5 Cooling – Operation time vs. energy consumption

To adjust the target parameters, a detailed capacity assessment and follow-up are needed.

The graphical representation of the information retrieved from Table 2 is presented in the subsequent figure (Fig. 6).

To clarify the meaning of these measurements, cooling falls between the range of 10-21% for 50% of the time. The demand for cooling capacity is only greater than a 42% load ratio (95th percentile) in 5% of cases, and the load ratio is greater than 57% of the total cooling capacity in only 1% of cases (99th percentile). The maximum load capacity was 76% of the total installation capacity. Therefore, in cooling, the system is oversized by about 24%.

Over the course of 76 days of testing, the total energy consumption reached approximately 4,151 kWh. An overview of the monthly energy consumption during this time period can be found in Table 3 and Fig. 7.

These values account for standby consumption, but do not include the consumption of indoor units.

5 Indoor unit consumption ratio

Fig. 8 provides an estimate of the total consumption ratio, with bars indicating the consumption per indoor unit in both cooling and heating modes.

Table 2 Results of experimental measurement

Maximum hourly average cooling capacity 38 kW			
Main load ratio range	Only 5% of a load ratio is higher than	Only 1% of a load ratio is higher than	Maximum load ratio
10–21%	42%	57%	76%

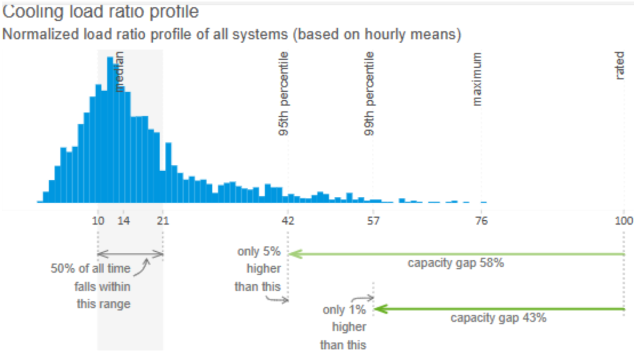

Fig. 6 Cooling load ratio profile

Table 3 Monthly energy consumption during experimental measurements

Total energy consumption 4,151 kWh				
Date: 07-2021	Date: 08-2021	Date: 09-2021	Date: 10-2021	Date: 11-2021
2,033 kWh	1,642 kWh	735 kWh	1,004 kWh	907 kWh

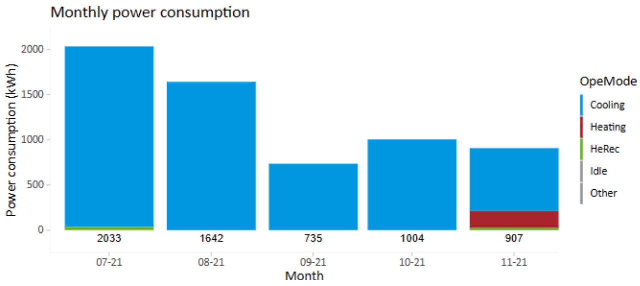

Fig. 7 Overview of the monthly energy consumption during the reported period

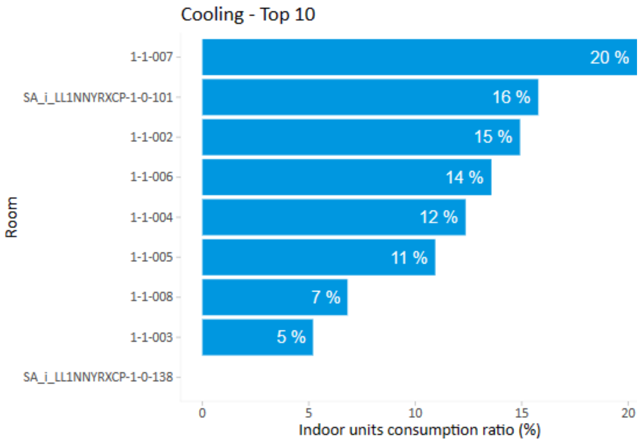

Fig. 8 Indoor unit consumption ratio

Here, it is possible to identify the areas with the highest energy consumption and concentrate on the spaces (rooms) with the greatest potential for energy savings.

Figs. 9 and 10 show images from the site of the experimental measurements.

6 Conclusion

This report is based on 76 days of online monitoring using the ITC control panel. Online monitoring enables more precise sizing based on real-life retail data. Pastry baking cycles, in fact, depend on the average age of customers and their habits. The older population prefers earlier shopping hours when outdoor temperatures are not as high, whereas the younger population prefers noon hours when they return home.

The peak heat loads from outside during 9^{00} a.m. to 1^{00} p.m. do not result in increased demand for fresh pastry. The retail team prepares fresh pastry during the afternoon hours (specifically between 2^{00} p.m. and 5^{00} p.m.). Consumer habits vary by location, which can lead to volatility and errors [7].

Fig. 9 Indoor unit installation (authors' archive)

Fig. 10 Outdoor condensing units (authors' archive)

The temperature setpoints offer significant potential for savings. Based on these findings, all setpoints for internal units are adjusted to 23 °C. The acceptable temperature in the baking area is up to 26 °C. Adjusting the setpoint of two units enables a reduction of up to 30% in the energy consumption of respective indoor units. The baking area's total energy consumption amounts to around 36% of all the indoor units.

Acknowledgement

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