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Optimizing the Power Usage of Anti-Sweat Heaters in Glass-Door Refrigerators According to the Dew Point

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Abstract: Putting glass doors on the display cases of refrigerators is one of the most efficient ways to reduce the energy consumption of supermarkets. However, the glass fogs up when opening the door because of the difference in air temperature inside and outside of the refrigerator, thereby obscuring the view. To defog the glass, anti-sweat heaters (ASHs) are used. In this paper, the power usage of ASHs according to changes in the dew point (DP) inside a supermarket were evaluated for two types of ASH, i.e., the door-frame ASH and the glass ASH. The evaluation was based on measurements of the condensation on the glass doors of vertical display cases, used for the preservation of frozen foodstuffs. A mathematical model of the correlation between the ASH's power usage and the DP was developed and used for predicting the long-term energy savings. The savings were calculated based on the measured DPs inside the supermarket, which were extrapolated over a longer time period based on their correlation with the outside DPs. Regulating the door-frame ASH according to the DP resulted in an 84.6% reduction in energy consumption and a 90.1% reduction in the case of the glass ASH, compared to the current state. The correlation between the DPs inside and outside the supermarket served as a basis for the proposed implementation of the power usage regulation of the ASH according to the DP.

Keywords: anti-sweat heaters; condensation; glass-door refrigerators; dew point; energy savings

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1. Introduction

The demand for electrical energy is continuously increasing. There are at least two strong motivating factors driving research towards a reduction in energy consumption: (i) an increase in the environmental awareness in society because of the effects of global warming, and (ii) high energy costs, which represent a significant fraction of companies' operating expenses. Thus, reducing energy consumption will have direct ecological and economic benefits [1–3].

Supermarkets are large consumers of electrical energy: it is estimated that they can account for up to 3% of a country's energy consumption [4]. From 23% to as much as 80% of a supermarket's total consumption is a result of refrigeration needs [5,6]. Hence, refrigeration has a large potential for optimization, resulting in economic and energy savings [7,8]. The energy consumption of refrigerators can be reduced by the placement of doors on open display cases. In this way a reduction of 25%, to as much as 80%, in energy consumption can be achieved [9–11]. This is also beneficial for the safety of the preserved food because all the products can be maintained at the same temperature. Placing doors on the cases also decreases the need for the defrosting of refrigerators and the heating of supermarkets [9,10]. Therefore, in more and more countries glass-doored cases are compulsory because of all the benefits associated with the safety of food and energy consumption [12,13].

However, there is also a downside to their usage. The glass fogs up when opening the door because of the difference in the air temperature inside and outside the refrigerator, obscuring the view of the products [5,10,14]. It takes a considerable amount of time for the glass doors to defog without an external influence. The defogging process can be sped up using two methods. One is by employing anti-fog films (AFFs) and the other is with anti-sweat heaters. The AFFs do not consume any additional energy for defogging. Despite this, their usage is not widespread as they are expensive and do not yet provide adequate results [2]. Their defogging times are longer compared to ASHs [15] and they also lack durability as they are easily damaged, resulting in a loss of their anti-fogging abilities. This might change in the future because recently a plethora of research with novel findings were made on this subject [16,17]. ASHs provide a more efficient way of defogging as they can speed up the defogging process by as much as three times [15,18]. The ASHs heat up the glass above the dew point, ideally preventing condensation on the surface of the glass. This is achieved either with the use of a door-frame ASH or a glass ASH. Door-frame ASHs are heaters placed in the door frame of the glass doors, thus they heat the glass from the edges. The glass ASHs, on the other hand, are made from electrically conductive transparent material, which is integrated into the glass itself. Therefore, they heat up the whole glass surface evenly. Glass ASHs are more expensive than the door-frame ASHs, but they provide better results. With the development of new and cheaper materials for glass ASHs their use is becoming more widespread [19,20].

ASHs represent an additional electrical load on the refrigerator, which consists not only of their energy consumption but also of the additional power need for the refrigerator to transfer the heat produced by the ASH. Nonetheless, the doored display cases with the use of ASHs are estimated to consume approximately 30% less energy than the open display cases [9]. In most supermarkets the ASHs are turned on for the whole day and are switched alternately on and off during the night to save energy. However, there is no need for them to work at full power, even during the day, because of the changing relative humidity (*RH*) in the store and, consequently, the changing DP [2,21]. The environmental conditions in a supermarket change considerably during the day and even more during the year. This happens to some extent even if heating, ventilation, and air conditioning (HVAC) systems are used, which is rarely the case, especially in smaller businesses because of the cost inefficiency [2,22].

The energy consumption of ASHs can be reduced by adjusting their working regime to the environmental conditions, thus saving on energy. It is estimated that by adjusting the power of the ASH to the DP inside a store, a reduction of 30% to 40% in the energy consumption of the ASH can be achieved [2,14]. There has been some research in regard to the speed of defogging [13,15,23], but the issue of energy consumption has not yet been thoroughly addressed.

According to the literature review, there is a lack of studies systematically addressing the optimization of the power usage of anti-sweat heaters in glass-door refrigerators according to the dew point from measurements of the parameters in the supermarkets. This subject is recognized as very important from the point of view of reduction of power consumption and cost optimization.

In this work, the correlation between the energy consumption of an ASH and the DP of a refrigerator with vertical display cases, used for the preservation of frozen foodstuff, was calculated by employing a mathematical model for the condensation on a glass-doored case. The model was based on measurements of the power usage and the condensation. With the correlation between the power usage of the ASH and the DP, energy savings for both types of ASH were evaluated and extrapolated to predict the long-term benefits. The implementation of the ASH's power regulation according to the DP was proposed.

2. Methods

To optimize the power usage of the ASH according to the DP, a model of the condensation on a glass-door display case of a refrigerator was developed based on natural laws of the process and measurements taken in a real environment.

2.1. Condensation

In order to describe the condensation that took place on the glass doors of display cases, the physics of condensation and the parameters of the refrigerator influencing the condensation were taken into account. The parameters were based on empirical measurements of the correlation between the ASH's power usage and the DP.

2.1.1. Physics of Condensation

Condensation occurs when the temperature of the air is lower than its DP, meaning *RH* is at 100%. When the air condenses, droplets of water form on the surfaces that are colder than the DP, meaning that, in the case of a glass surface, the accumulated fog obscures the view. If the coldest areas of glass remain heated to a temperature greater than the DP, there should be no fog formation.

The DP of the air is dependent on the amount of moisture in it and can be calculated by using the August–Roche–Magnus approximation [24] described by Equation (1):

$$T_{\mathrm{DP}} = \frac{A\left[\ln\left(\frac{RH}{100}\right) + \frac{B\cdot T}{A+T}\right]}{B - \ln\left(\frac{RH}{100}\right) - \frac{B\cdot T}{A+T}} \tag{1}$$

where A and B are constants with the values A = 243.04 °C and B = 17.625. T [°C] is the temperature, RH [%] is the relative humidity, and T_{DP} [°C] is the dew point temperature of the air. To calculate the DP, only the temperature and the *RH* of the air have to be measured.

It is very difficult to completely prevent condensation because dynamic effects need to be taken into account. An example of this is the opening of a glass door of a refrigerator. When opening the door, air masses with different temperatures and water vapor contents begin to mix. This process is likely to cause fog to form on the glass. Hence, by heating the surface at a given DP of air, only the stationary conditions (e.g., when the refrigerator is closed) and the time required to reach them can be influenced. These correlate with the coldest temperature of the glass surface, which should be heated just above the DP to achieve a defogged stationary condition in the required time.

2.1.2. Measuring Condensation

In order to predict the energy savings, the process of condensation on the glass doors of a refrigerator was measured in a mid-sized supermarket located in Slovenia. The refrigerator was used for the preservation of frozen foodstuffs. It had six double-layered glass doors, each 56 cm wide and 143 cm high. Each door had a door-frame ASH, with a nominal power of 55 W. Its manufacturer claimed that such power should be enough to keep the glass door defogged at an air temperature of 25 °C and 60% *RH*, which represented air with a DP of 16.7 °C.

A testing procedure for measuring the process of condensation depending on the ASH's power consumption was agreed using the observation of condensation in a real environment and data from [16].

The testing procedure consisted of the following:

- ASH power adjustment,
- waiting for the temperature of the glass door to stabilize,
- analysis of the testing conditions before the measurements,
- *RH* and temperature measurements,
- opening of the glass door for a predefined amount of time,
- measuring the time needed for the glass door to defog.

The testing procedure began by adjusting the operating power of the ASH. After setting the ASH's power for the measurement, a given amount of time must have passed before the measurements could be made. This was caused by the heat capacitance of the glass door, which delayed the measuring process by the amount of time it took the glass-door temperature to reach a steady state. Since the temperature settling time was dependent on the amount of change in the ASH's operating power and surrounding outside air temperature, the glass door needed to be inspected every time before conducting measurements, to ensure the same starting point for each individual measurement. The measurement process itself started by measuring the surrounding air temperature and the relative humidity 1 m above the floor and 1 m away from the glass door. This was followed by opening the refrigerator's door and exposing the inside glass-door surface to the hotter and more humid outside air. The glass door was kept open for 30 s, which represented the maximum realistic duration of a customer opening the door. Lastly, the time it took for the glass to defog was measured. Stationary conditions should be reached during this time, at which point the glass door was no longer covered with fog. The defogging time was measured up to 180 s.

Using Equation (1) the DP of the air could be calculated from the measured *RH* and temperature. Assuming the absolute humidity inside and outside the refrigerator were equal, the correlation between the energy consumption and the DP could be derived with the described testing procedure by measuring the defogging time.

If the measured time of defogging was longer than 100 s, the power of the ASH at the measured DP was deemed inadequate, as the defogging process was too long to reach stationary defogged conditions (if at all). On the other hand, if the measured time was shorter than 100 s, then the power of the ASH could be lowered to keep the glass defogged in the prescribed time. The cut-off time of 100 s for complete defogging was based on the data in [18], where experimental results showed a defogging time of 50 s after opening the door for 15 s. The cut-off time for defogging after the maximum duration of door opening was also in accordance with consumers' shopping experience and the frequency of door openings.

To adjust the ASH's power consumption, its electrical resistance was measured under its nominal working conditions with a Fluke Norma 4000 power analyser (Everett, WA, USA), boasting a 0.2% measurement accuracy. The ASH's power was adjusted by changing its power supply voltage, measured with an Agilent U1252A multimeter (Santa Clara, CA, USA). The latter has a voltage measurement accuracy equal to $\pm$0.5% + 5 LSD, relating to approximately 1 V. To measure the air temperature and the *RH* in the vicinity of the refrigerator, an Ebro EBI 20-TH1 device (Ingolstadt, Germany) was used, with a $\pm$0.5 °C and $\pm$3% temperature and *RH* measurement error, respectively.

2.2. Modeling and Simulation

In order to define the correlation between the ASH's power usage and the DP, the process of condensation was simulated. The parameters of the simulation were based on the empirical measurements of the correlation between the ASH's power usage and the DP. The defined correlation was used to estimate the energy savings.

2.2.1. Simulation of Power Usage

A 3D computational fluid dynamic analysis was set up using Dassault Systèmes Solidworks to simulate and evaluate the correlation between ASH energy consumption and the lowest glass surface temperature. The simulation was carried out for the refrigerator described in Section 2.1.2, Measuring condensation.

The simulation took into account 29 mm thick double-layer glass doors consisting of 2 mm thick glass with a thermal conductivity of 1.89 W/(m·K) and a 25 mm layer of air in between both glass layers. The refrigerator walls and the remainder of the door assembly were represented by a 25 mm wide polyurethane isolation with a thermal conductivity of 0.034 W/(m·K). All the thermal conductivities were calculated at 25 °C and in relation to the temperature. Homogenous heating around the edges of the glass was added to represent the door-frame ASH. The 2.54 m long and 0.002 m wide ASH was defined as a surface heat source with a heat generation rate ranging from 0 to 55 W, in steps of 5 W.

A homogenous temperature was assumed 5 cm away from the door to represent the frozen products that were kept at a constant −18 °C, in accordance with health regulations. The temperature outside the refrigerator was set to 20 °C, which was found to be the average inside temperature in the supermarket. Both laminar and turbulent fluid flow were taken into account, with the former defined as an I-L turbulence model with 2% turbulence intensity and 4.6 mm turbulence length. Minimum inner glass surface temperature convergence was the main analysis goal. The frontal view of the end result—inner glass surface temperature distribution—is shown in Figure 1, alongside a horizontal slice of the simulation mesh granularity. Several mesh configurations were explored on a simplified refrigerator model in order to reduce total analysis time, while still yielding minimal glass surface temperature results comparable to those obtained with the highest achievable mesh granularity. The final applied local mesh settings in the flow simulation were gathered and are shown in Table 1.

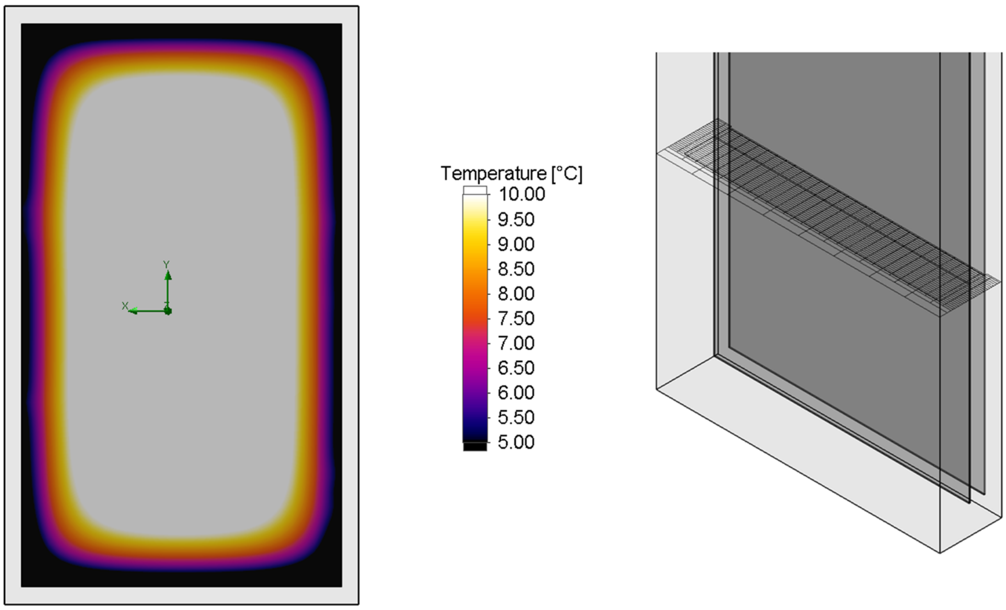

Figure 1. Simulation results for a 5W glass surface ASH. Inner glass surface temperature (**left**) and mesh granularity (**right**). The obstructing refrigerator body is hidden.

Table 1. SolidWorks flow simulation local mesh settings.

Local Initial Mesh Setting Name	Setting Value
Small solid features refinement level	2
Tolerance refinement level	3
Tolerance refinement criterion	0.00075 m
Level of refining all cells	3
Characteristic number of cells across a narrow channel	14
Narrow channels refinement level	3

The same parameters were used when assessing the same correlation between the ASH's power consumption and the coldest temperature of the glass surface, this time using homogenous heating of the entire 0.81 m high and 0.46 m wide glass surface and with the same heat generation settings. This represented the glass ASH, which was integrated into the glass itself.

2.2.2. Predicting Energy Savings

Energy savings were predicted based on the correlation between ASH power consumption and the coldest temperature of the glass surface. The coldest areas of the glass needed to be kept just above the DP in order to achieve satisfactory defogging times. Therefore, the optimal power usage of the ASH could be calculated knowing the current environmental conditions, which were summarized in the DP. For evaluating the energy savings of the proposed control of the ASH for a given time period, only the fluctuations of the DP needed to be known.

The energy savings were assessed for the supermarket in Slovenia with three refrigerators, each having six glass doors. The door-frame ASHs functioned at full power during opening hours, between 6 a.m. and 10 p.m., and were alternately switched on and off with a 50% duty cycle during the night. Week-long measurements of the inside temperature and the *RH* were taken in the supermarket in October 2016. From the measurements, the inside DPs were calculated using Equation (1) and compared to the outside DPs, which were calculated using measurements of the outside air conditions from the Slovenian Environment Agency (ARSO).

From the comparison between the DPs inside and outside the supermarket, an estimation of the inside DP relating to the outside DP could be made for months with similar weather conditions as the measured one. The estimation of the inside DP from the measurements of the outside DP was achieved by using a purposively developed algorithm, accessible in [25]. In this way the energy savings could be evaluated for a longer time period.

3. Results

The following sections report the results from the measurements of the process of condensation, the simulated correlation between the ASH's power usage and the DP, and an estimation of the energy savings with the use of the optimal power regulation for the ASH.

3.1. Measurements

Figure 2 presents measurements of the condensation depending on the door-frame ASH's power usage and the DP. They were conducted according to the procedure presented in Section 2.1.2, Measuring condensation. They were separated into two groups in accordance with the described cut-off defogging time. Figure 2 illustrates a trend between the adequate and inadequate defogging times, indicating a potential trendline that separated the two regions. However, manual measurements were subjected to measurement uncertainty due to visual classification of the glass being (de)fogged. Thus, it was difficult to define the exact correlation between the optimal ASH power and the DP. Therefore, the correlation was ascertained by simulating the glass heating process and defining a numerical goal—the minimal glass surface temperature, outlining a limit for the DP.

Note, that the measurements in Figure 2 were concentrated at higher DPs because of the environmental conditions at the measured location. To keep the glass defogged at higher DPs, the power of the ASH needed to be close to the nominal power. Hence, the majority of measurements were conducted at higher powers.

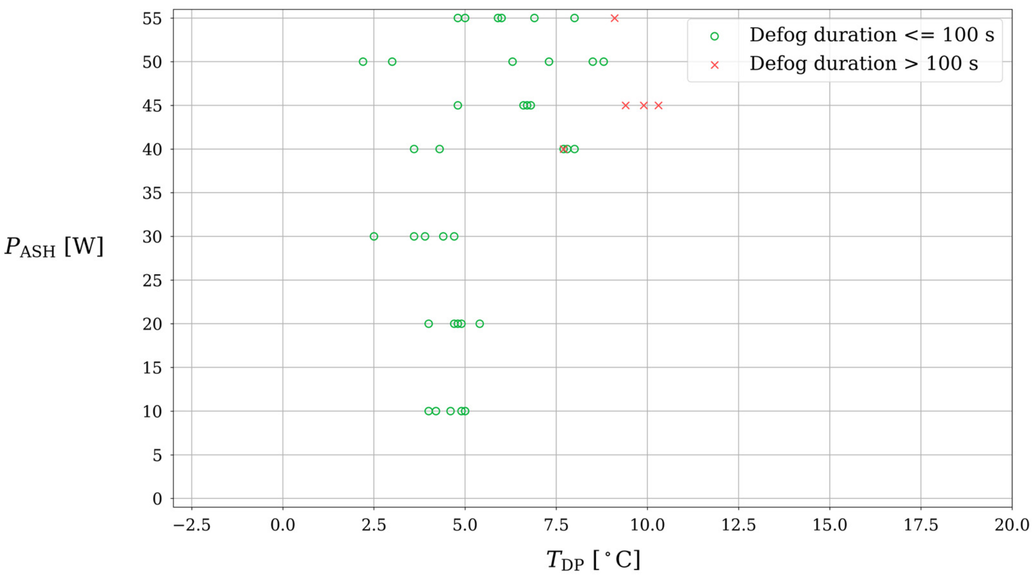

Figure 2. Measured correlation between a door-frame ASH's power usage and the DP.

3.2. Results of the Simulation

Figure 3 presents the results of the simulation of the correlation between the ASH's power usage and the coldest temperature of the glass surface for both types of ASH. If the minimal temperature of the glass was kept at a temperature just above the DP, the glass would be defogged when the stationary conditions were reached in the prescribed amount of time. For a comparison the measurements from Figure 2 were added.

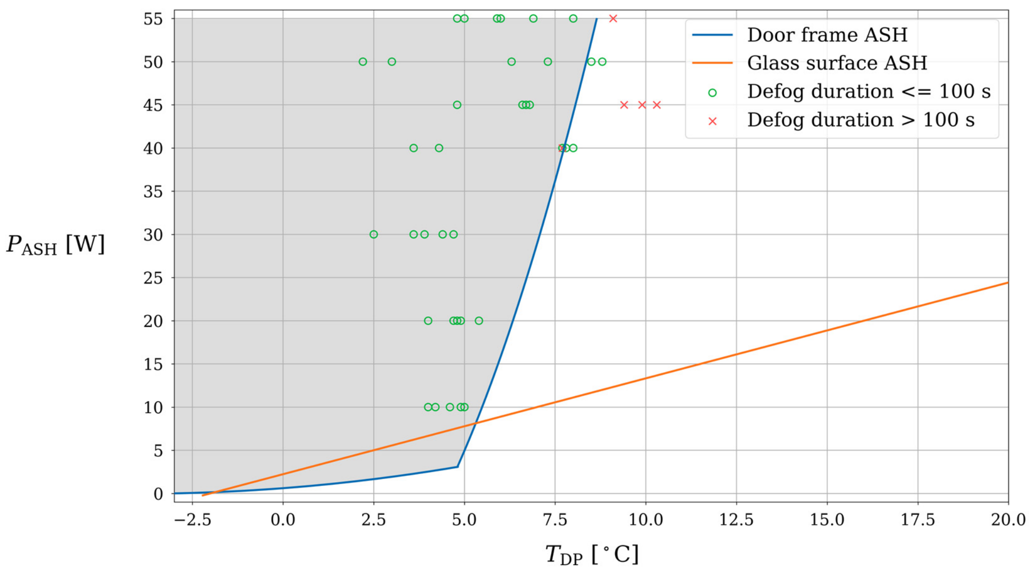

Figure 3. Comparison of the ASH's operating power vs the DP using a door-frame ASH and a glass ASH, with added measured data.

There is a discrepancy between the measured values and the defined correlation for the door-frame ASH. This was due to the inaccuracy of the measurements. The margin of error for the measurements was relatively large due to the difficulties in measuring the defogging time. The time of defogging was very dependent on the non-homogeneities in the air and on the glass, as well as its impurities, which increased the defogging time.

Figure 3 shows, that at high powers, the glass ASH achieved a higher minimal temperature of the glass at the same power compared to the door-frame ASH; thus, higher energy savings were expected with the use of glass ASHs. Nevertheless, it should be noted that at low powers the glass ASHs achieved lower temperatures of the glass than the door-frame ASHs. The frame of the glass doors was made of metal, which is a good thermal conductor and thus dissipated more heat. Therefore, the minimal temperature of the glass was achieved at the edges, when the heating of the glass was not applied from the frame, as in the case of the glass ASH. At low powers, the influence of the dissipated heat was such that the glass there achieved lower temperatures than with the use of the door-frame ASH. However, this only happened for a narrow area around the edges, where fog formation was not very obtrusive for the customers. Therefore, 1 cm around the edges was disregarded while evaluating the relation between the power usage of the glass ASH and the lowest temperature of the glass door frame. The calculated relation was in the form of Equation (2):

$$P_{\mathrm{ASH_{glass}}} = 1.11T_{\mathrm{DP}} + 2.23 \tag{2}$$

The same correlation with the use of the door-frame ASH was different and is represented by Equation (3):

$$P_{\mathrm{ASH_{frame}}} = \begin{cases} 0.04{T_{\mathrm{DP}}}^2 + 0.32T_{\mathrm{DP}} + 0.61; -2.59 < T_{\mathrm{DP}} \leq 4.82 \\ 1.06{T_{\mathrm{DP}}}^2 - 0.75T_{\mathrm{DP}} - 17.8; 4.82 < T_{\mathrm{DP}} \end{cases} \tag{3}$$

With the deduced correlations represented in Equations (2) and (3), the optimal power usage for a given DP of air to achieve defogged stationary conditions in the prescribed amount of time could be calculated. Based on this, the energy savings could be evaluated.

3.3. Energy Savings

The measured values of the DP inside the supermarket for a given time period are represented in Figure 4. For comparison, the values of the outside DP were added. The changes in the inside DP closely followed the changes in the outside DP, but they were slightly delayed. Based on this, a correlation between the inside and outside DPs was estimated for a time frame with similar weather conditions as in the time of the measurements in order to predict long-term energy consumption. The most probable course of the extrapolated inside DP based on the correlation with the outside DP is shown in Figure 5. Note, that the time delay might be different based on the particular environment, supermarket insulation and ventilation, and refrigerator placement within it.

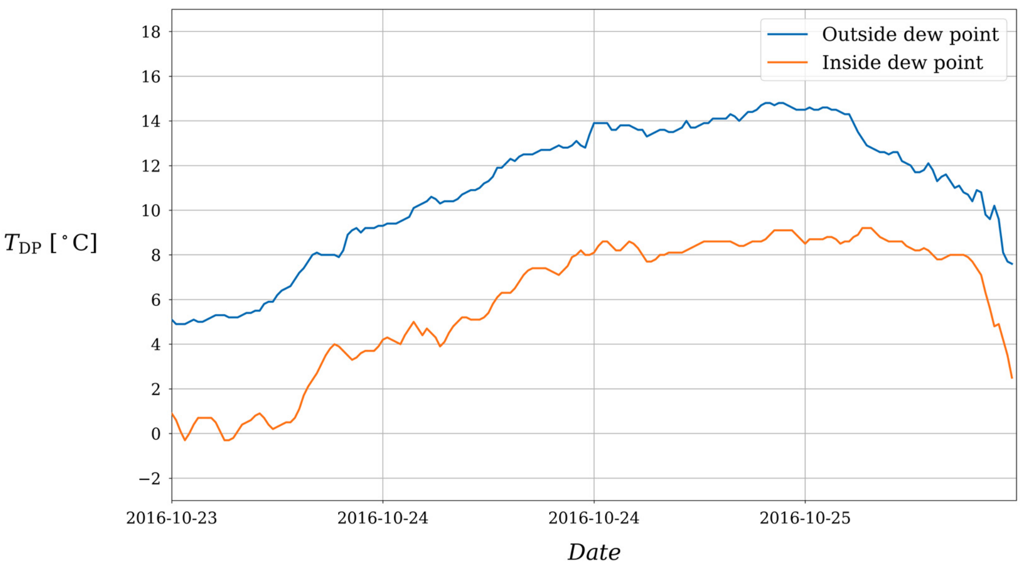

Figure 4. Measured DP inside and outside the supermarket.

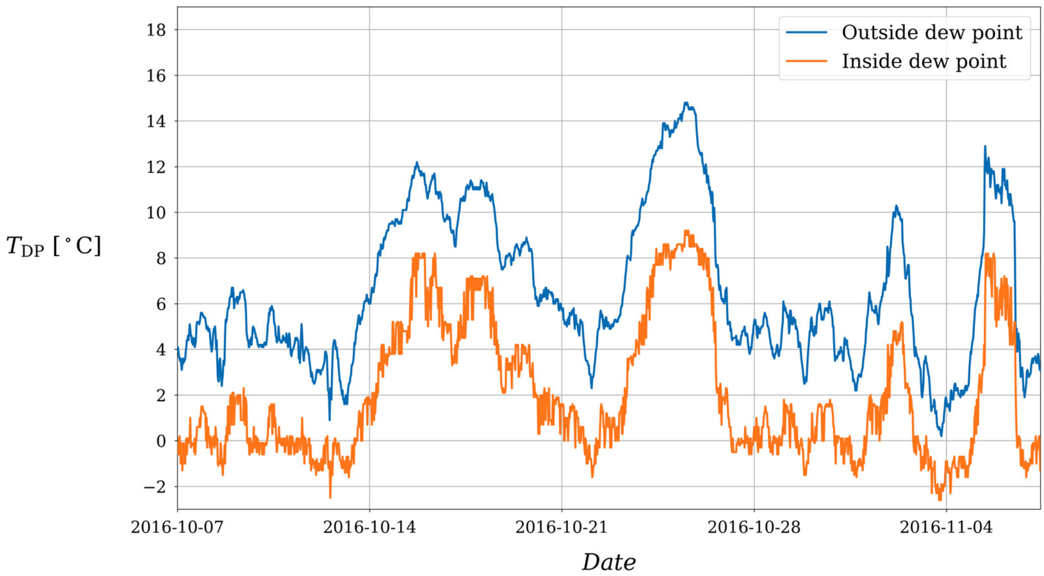

Figure 5. Extrapolated inside DP based on the outside DP.

Based on the extrapolated values of the inside DP, presented in Figure 5, the optimal power regulation for the ASH could be evaluated using the relationships represented in Equations (2) and (3). A fraction of the optimal power regulation in the given time period is shown in Figure 6 for both types of ASH. The current state of power usage was added for comparison.

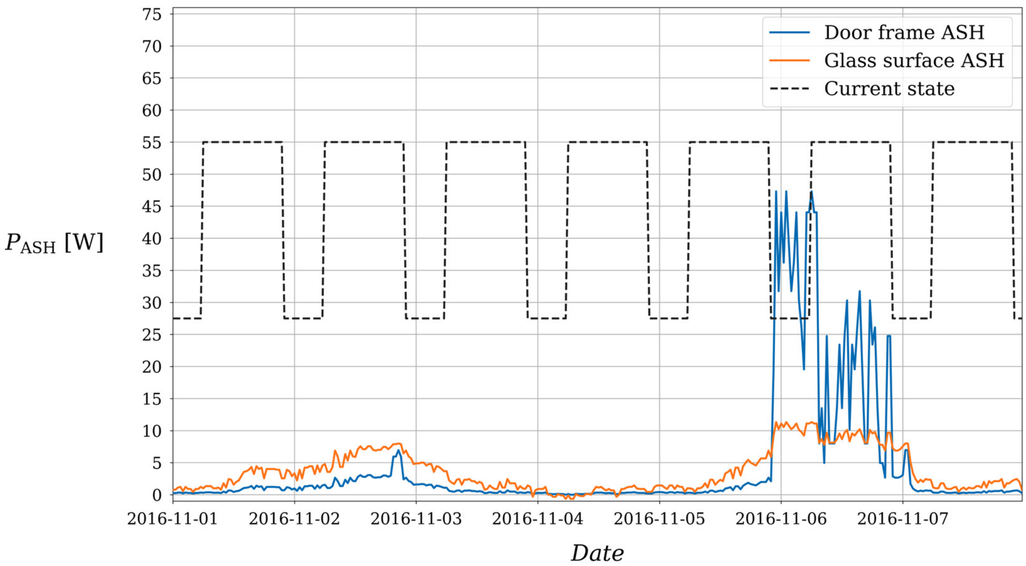

Figure 6. Optimal power usage according to the DP for both types of ASH.

The proposed power regulation of the door-frame ASH according to the DP results was an 84.6% reduction in energy consumption compared to the current state. If glass ASHs were used, the energy savings were even greater, i.e., 90.1%. Taking into account six doors per refrigerator and three refrigerators for frozen foodstuffs in the supermarket, that accounted for a total of 536 kWh and 571 kWh of saved energy, respectively. Considering the average prices of electricity for industrial consumers in Slovenia from 2016 (i.e., 85 €/MWh), energy savings in the given time frame of one month would result in €45.6 lower costs if door-frame ASHs were used, and €48.5 in the case of glass ASHs.

Figure 6 clearly illustrates that current regulations for the supermarket is such that door-frame ASHs function at 50% of peak power at night. By not limiting the power usage at night, the need to wipe the accumulated fog in the morning could be prevented (if the DPs during the night were high). If wiping the glass in the morning did not represent a problem, then the power usage at night could be limited to 50% peak power, thus additionally increasing the energy savings. However, this should be avoided in very humid conditions, where a large amount of condensed water on the glass could freeze during the night, causing other difficulties.

4. Discussion

This study found that with the use of the right ASHs and their optimal power regulation according to the DP, energy consumption could be reduced by up to 90.1%, compared to the current state. A reduction in the power usage of the ASH also had additional benefits. With the reduced power usage, less heat was dissipated in the refrigerator, thus less heat needed to be transferred from it. Therefore, the power usage of the whole refrigerator could be further decreased, resulting in even larger energy savings.

Glass ASHs achieved better results than door-frame ASHs, especially in areas with higher DPs, i.e., areas with tropical weather. The former were more efficient because they heated the glass more evenly than the latter. Therefore, the minimal temperature of the glass was higher compared to the door-frame ASHs (Figure 5). The advantages of glass ASHs could be seen in Figure 6, where the necessary peak values of the energy consumption for the glass ASHs were substantially lower than those of the door-frame ASHs. Higher maximum temperatures also meant the glass ASHs produced satisfactory results even at higher DPs, which were achieved in humid weather conditions. As seen, weather conditions could vary greatly, thus the ASH's power should be regulated accordingly.

In this study, it was assumed that the DP inside the whole store was constant, thus a single measurement of the temperature and relative humidity sufficed for its estimation. However, certainly discrepancies could be met in a real-world situation (especially when considering the effects of customers). These details presented an interesting direction for future research.

The main issue with implementing regulations for ASHs is the duration of heating the glass. Sudden changes in the inside DP required substantial changes in the ASH's power as well. The glass needed to achieve the required temperature for adequate defogging times quickly enough in order to follow the changes in the inside DP. The changes in the inside DP could be quicker than the process of heating the glass to sufficient temperature. The problem was more severe with the use of a door-frame ASH, as they heated the glass only from the edges. Glass ASHs achieved better results in this aspect as well as they distributed the heating more evenly, causing faster heating of the whole surface, thus faster defogging times.

The proposed solution to the regulation problem was to anticipate the changes in the inside DP and adjust the ASH accordingly beforehand. For this, the prediction of the course of the inside DP according to the outside DP could be used. The time delay between the outside and inside DPs was similar to the time for the glass to achieve the maximum required temperature changes. In order to accurately predict the changes in the inside DP according to the outside DP, the model of their correlation should be improved with measurements of both values for all of the most common weather patterns. The correlation was also influenced by the number and frequency of customers inside the supermarket, which ought to be included in the model. This modeling remains an open issue for future work that can employ artificial intelligence-based techniques [26] to search for the correlation between the inside and the outside DPs for a specific supermarket's location. For example, a random forest or support vector regression model would allow the inference of the inside DP based on the instantaneous outside DP, while long short-term memory recursive neural networks excel at predicting target variables (inside DP) based on trends in time-series input data (outside DP).

A detailed study of the correlation between the inside and outside DPs presents the first step for a supermarket to implement the proposed regulation of power usage for the

ASHs according to the DPs. For that, only the temperature and the *RH* inside and outside the store have to be measured. The measured data should then be implemented in the control of the ASH. The implementation of the proposed solution represented only a small financial investment and was very cost-efficient as the expected return on investment was quick. For best results, glass ASHs were recommended; however, satisfactory results could also be achieved with the door-frame ASHs. The former were more expensive than the latter, but this might change in the future as the use of transparent glass ASHs is becoming more widespread, mostly in the automotive industry, and thus prices are expected to fall.

Another possibility to mitigate the effects of fogging of glass surfaces in refrigerators is with the use of horizontal display cases. Warmer air masses in the cases rise and heat the glass doors to a higher temperature, thus helping to prevent the formation of fog. In very humid conditions ASHs need to be used as well. Such solutions were used in some supermarkets, although their use might not be as appealing and attractive to consumers compared to vertical display cases.

5. Conclusions

This work evaluated the power usage of ASHs according to changes in the environmental conditions, summarized by the changing DP inside a supermarket. An assessment was conducted for two types of ASH: a door-frame ASH and a glass ASH. The evaluation was based on measurements of the condensation on glass doors of vertical display cases, used for the preservation of frozen foodstuffs. Thereafter, a mathematical model for the correlation between the ASH's power usage and the DP was developed. The model was used for predicting long-term energy savings. The savings were calculated based on the measured DPs inside the supermarket, which were extrapolated over a longer time period based on their correlation with the outside DP. Regulating the door-frame ASH according to the DP gave an 84.6% reduction in energy consumption and 90.1% in the case of the glass ASH. The correlation between the DPs inside and outside the supermarket served as a basis for the proposed implementation of the regulation of power usage of the ASH according to the DP. Some issues still remain open: the problem of how to define and measure the defogging process status as well as the uncertainties of inside DP prediction. These uncertainties do not influence the proposed framework for controlling ASH as such, but present a trade-off between achievable energy savings and satisfactory defogging performance.

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