

Managing the cooling demand of logistics processes by The minA Concept

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The case of a domestic refrigerator

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2012-11-13, Győr

Abstract

The logistics industry has huge cooling energy demand as there are many storage locations and transport actions “from the field to the table”, and there are cooling needs to keep the products in fresh and good conditions during logistics activities. “The minA Concept” is based on our wire-logistics approach: according to the real nature of the cooling demand through the supply chain it is possible to provide electricity infrastructure savings.

Applying “The mina Concept” as demand side management technique in modifying the daily load profile of the electricity network can help system operators in shifting the supply system to a more sustainable state.

In the actual phase of our research at Szabó-Szoba R&D Laboratory at Széchenyi University Győr we are focusing on the control of a domestic refrigerator to prove the feasibility of the concept. In our essay we present the test procedures and the results of the measures.

Index Terms— Demand Side Management, Domestic refrigerator, Green Logistics

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1 INTRODUCTION

Electricity-driven cooling is one of the most important consumer profiles – the world is using more and more electricity for these purposes (residential, industrial). The logistics industry has huge cooling energy demands as there are many storage locations and transport actions “from the field to the table”, and there are cooling needs to keep the products in fresh and good conditions during logistics activities.

Cooling has a year-by-year growing part in total electricity consumption, especially in summer time. Industrial cooling is not changing as much during the year, but the electrical power need for the same cooling energy is increased in this period, because ambient temperature is higher. There were many new air conditioner installations in residential areas and bureaus, offices and shopping centres in the previous decade, so the summer peak electricity demand reaches nearly the winter maximum (Földesi, Bódis, Bajor, 2012).

“The minA Concept” is based on our wire-logistics approach: according to the real nature of the cooling demand through the supply chain it is possible to provide electricity infrastructure savings. Applying “The minA Concept” as demand side management technique in modifying the daily load profile of the electricity network can help system operators in shifting the supply system to a more sustainable state.

In the actual phase of our research at Szabó-Szoba R&D Laboratory at Széchenyi University Győr we are focusing on the control of a domestic refrigerator to prove the feasibility of the concept. In our essay we present the test procedures and the results of the measures.

Electricity supply is a special super-pull logistics system. National electricity supply grids are constructed and re-engineered for the annual peak consumption. The results of overdesigning are high infrastructure construction and operation cost, also unutilized capacity in the same time. Our wire-logistics approach deals with demand side management and renewable electricity applications to smooth the daily electricity profiles.

Beside industrial, commercial and residential cooling the food industry has huge cooling energy demand in the extended agricultural supply chain. There are many storage locations and transport actions “from the field to the table”, and there are cooling needs to keep the products in fresh and

good conditions during logistics activities. Transporting and warehousing agricultural products requires special climate conditions, sometimes heating, but more often cooling performance. It is important to note, that in a warehouse, where fresh and frozen food is stored, the electricity demand of the cooling system is more than 60% of the total consumption.

2 THE IMPORTANCE OF DAILY ELECTRICITY LOAD PROFILE

The power and energy industry – in terms of economic importance and environmental impact – is one of the most important sectors in the world, since nearly every aspect of industrial productivity and daily life are dependent on electricity. Renewable energy provides clean and sustainable approaches to energy production, helps to ensure security of energy supply, and contributes to the meeting of the Kyoto Protocol objectives.

From the customer side, availability of electrical energy is indispensable - the main function of traditional electricity supply is to serve the consumer demand with solidly available (security of supply) and satisfactory (quality of supply) electrical energy (with adequate frequency and voltage). For the system operator it requests the integration of different sources (the base-load, the regulated and the non-regulated power stations, the fluctuating renewable wind and photovoltaic energy and in the future vehicle-to-grid units) and switch to the optimal network topology, in accordance with changing demands – known as unit commitment problem (UC). (Földesi, Baricza, Kiss, Vas, Bajor, 2010).

The new challenges in electricity supply, like de-regulation, distributed generation (co-, tri- or multi- generation) and electricity storage needs new theoretical approaches from the viewpoint of logistics. Decentralized electricity production and the introduction of variable, fluctuating (renewable) sources and transportation needs (electric vehicles) increase the difficulty of stabilizing the power network, mainly due to a supply-demand imbalance. It is therefore convenient to generate the energy, transmit it, convert it, and then store it if need be. Although there are various commercially available electrical energy storage systems, no single storage system meets all the requirements today. (Földesi, Baricza, Kiss, Vas, Bajor, 2010).

Unit commitment with renewable electricity sources and electrical energy storage is more complex than typical UC of conventional generating units, as the number of variables is much

higher than in typical UC problems, and both cost and emission should be minimized. From the measurements of the available renewable sources it can be clearly seen that the fluctuation of the solar and wind sources could not have been well predicted. For higher utilization of these sources there is a strong need for electricity storage solutions, or some new aspects of demand side management techniques which we are investigating.

National electricity supply grids are constructed and re-engineered for annual peak consumption. The results of overdesigning are high infrastructure construction and operation cost, and also unutilized capacity in the same time. Our wire-logistics approach deals with demand side management and renewable electricity applications to smooth the daily electricity profiles.

This concept contains two main behavioural patterns.

- Transfer - moving the peak consumptions to the valleys (decreasing the fluctuation)
- Kinetic - decrease the gradient changes during the day

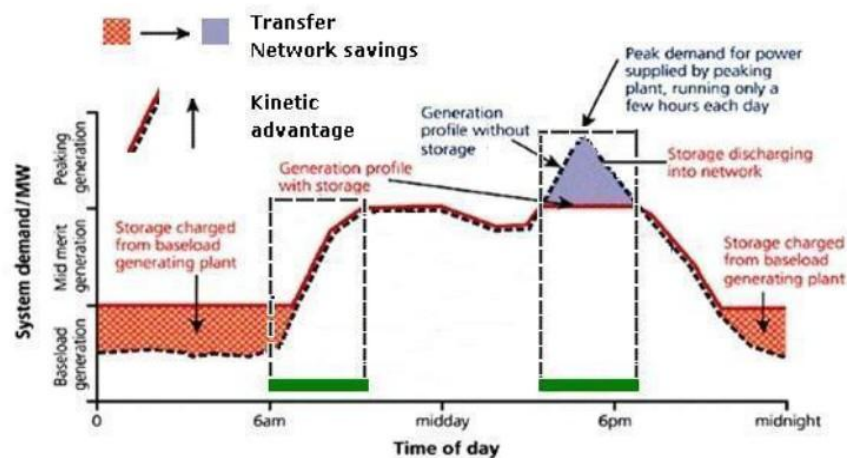


Figure 1. The average daily electricity load profile – with the critical intervals at the morning upload and the evening peak period (P. Földesi et al.)

3 MANAGING THE COOLING DEMAND BY THE MINA CONCEPT

There are many new development pathways for having smart refrigerators – we can imagine one that is equipped to sense what products are being put into it, and may even be able to determine when a product needs to be replenished. The refrigerator may even be able to send alerts when the food reaches a point where it may be spoiled. This alert may be displayed on the refrigerator's screen or may be sent to a computer via e-mail. The smart refrigerator keeps track of what is in stock through a couple of different methods. The method chosen often depends on the technology available on the food package. Given the fact that the smart refrigerator is still largely in the experimental stages, the technology is still evolving (for example RFID systems for automatic recognition and tracking).

There are widely available pure technical developments, like having better insulation or more efficient compressor unit, which consumes less electricity and performs better between part-load conditions, etc.

Finally, we were not able to find any contribution in the literature dealing with the daily consumption profile of the domestic refrigerator.

Electricity supply systems suffer from the fluctuation of demand – without or just with little portion of storage, this super-pull systems have to be agile, from the wire-logistics viewpoint.

In this way, overdesigning the production, transmission and distribution system is required to be able to provide for the actual consumer demand moments-from-moments, according to our lifestyle.

When we wake up, maybe the first thing is turn the light on – this need is elementary. After, during breakfast preparation, we usually open the door of the fridge, generally more than 3 times, and for more than 2 minutes – and after closing the door, we can see that the compressor switched on (the temperature reached the thermostat settings). As can be clearly seen on the profile, this period has the highest kinetic challenge – any saving we can reach in this “morning upload and peak” window provides huge benefit (the operation in the traditional way is very expensive - without fulfilling the needs from storage, like hydropower – the national grid's system operator has to start expensive additional power plants, etc).

The main idea of “The minA Concept” is to shift this demand to another, GridfRiEENd (grid-friendly) period (Földesi, Hegyi, Bajor, 2011). Naturally, this type of demand side management technique can be acceptable if the limitation does not affect the quality of food in the refrigerator.

For applying “The minA Concept” in a case of a simple domestic refrigerator, we installed a brand-new Gorenje RF3184W type fridge in Szabó-Szoba R&D Laboratory. The purpose of the research is to investigate which type of “variable setpoint strategy” can help in smoothing the daily electricity profile of households and shift the cooling demand from critical periods to non-critical intervals. In the actual phase of our investigation we are focusing on substituting the conventional "thermostat-driven" control to a "microcontroller-driven, product temperature based" one to prove the feasibility of the concept.

During the test procedure our Gorenje refrigerator is completed with a York-ISON microcontroller for monitoring system parameters such as 6 analogue inputs for temperature sensors and additional 2 digital inputs, like:

1. outside air temperature sensor (OUT-AIR),
2. refrigerator air temperature sensor (RFG-AIR),
3. freezer air temperature sensor (FRZ-AIR),
4. vegetable box air temperature sensor (VCM-AIR)
5. perishable product temperature sensor (PRS-TMP, a piece of bacon),
6. liquid product temperature sensor (DRN-TMP, a bottle of beer in the middle of the refrigerator),
7. door opening contact (DOP-STA)
8. refrigerator thermostat status (THR-STA)

The York ISON microcontroller drives the only digital output for starting the compressor. During thermostat-driven control strategy the microcontroller passes the incoming signal to the compressor with 10 seconds delay, during peak limitation and minA strategy there are other system parameters required to start cooling (time window enabled, temperature of the liquid reaches a given level, etc).

A laptop computer was connected to the microcontroller to manage the operations and log measurements in every minute.

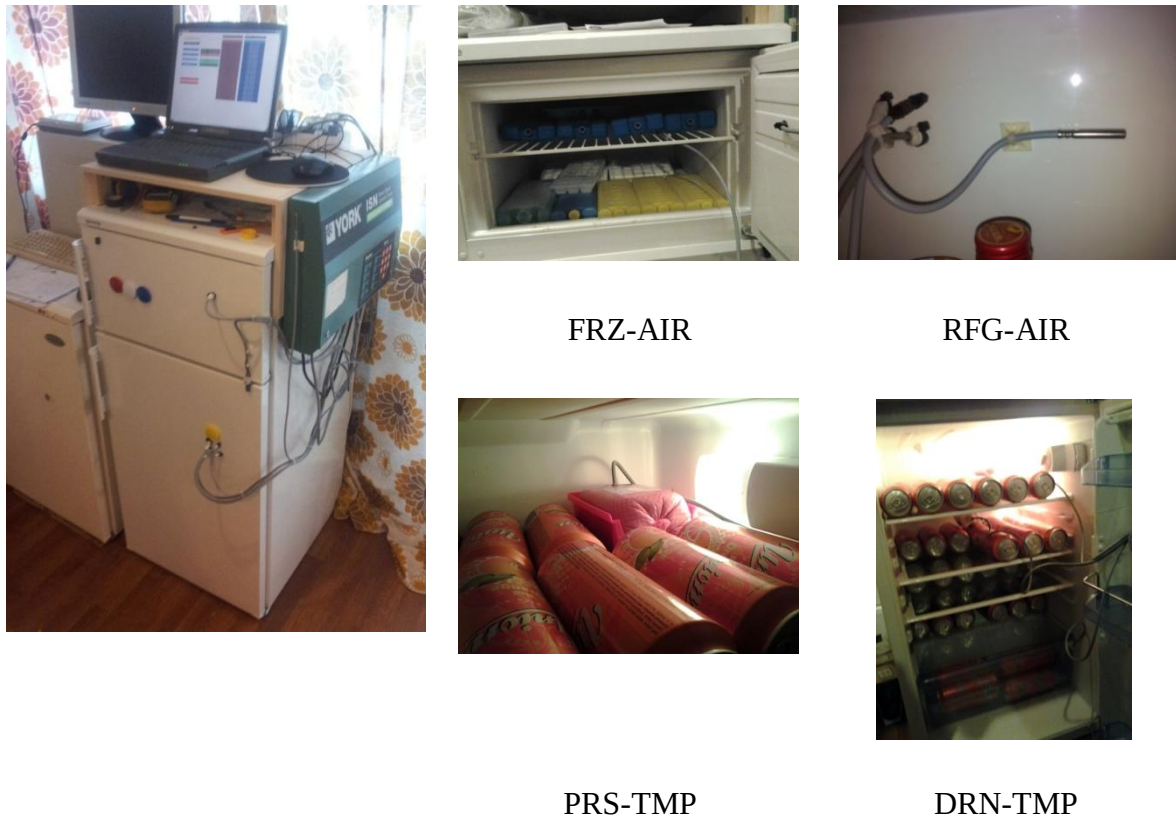


Figure 2. The minA test environment

In the first phase of the investigation we made tested to recognize the thermostat-driven switching points related to product temperature distribution with different manual settings. As a result we got the thermostat-driven temperature profile of different settings near a given load (in our further research we will test the impact of door openings and various loads).

The cooling process has different gradients where we consider different product or air temperature values, according to different thermal inertia and heat capacity.

4 RESULTS OF ACTUAL INVESTIGATIONS

In the actual phase of the research we demonstrate the effect of applying “The minA Concept” with “microcontroller-driven, product temperature based” control:

- the base signal is the DRN-TMP value
- setpoint varies during the day with $\pm 0.5^{\circ}\text{C}$ “switch on – switch off” tolerance
- the pre-cooling setpoint is $+3.0^{\circ}\text{C}$ from 0 to 6 hrs
- the normal setpoint is $+5.0^{\circ}\text{C}$ from 9 to 16 hrs
- the emergency cooling setpoint is $\pm 9.0^{\circ}\text{C}$ from 6 to 9 and from 18 to 20
- the peak limitation period is from 17 to 18 and 20 to 21

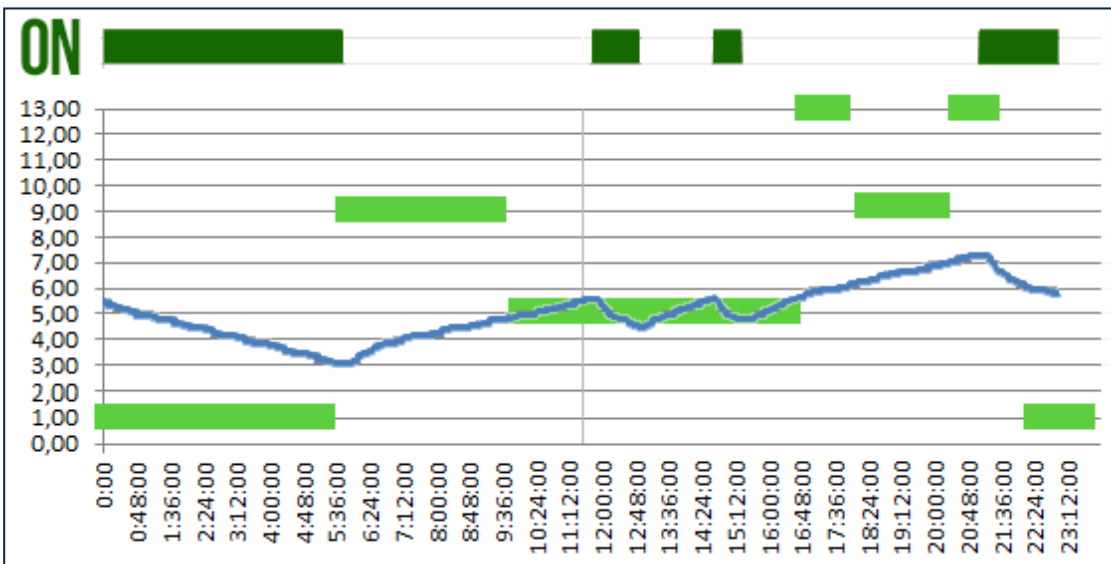


Figure 3. DRN-TMP daily temperature profile with applying “The minA Concept”

Based on “The minA Concept” it is possible to reduce the number of switching operations, which can extend the lifetime of the compressor unit and reduce the maintenance cost. Otherwise we have to accept wider tolerance in the temperature profile.

Applying “The minA Concept” often requests longer operation intervals of the compressor unit for cooling the products in the normal space, but in the same time the freezer can be over-cooled.

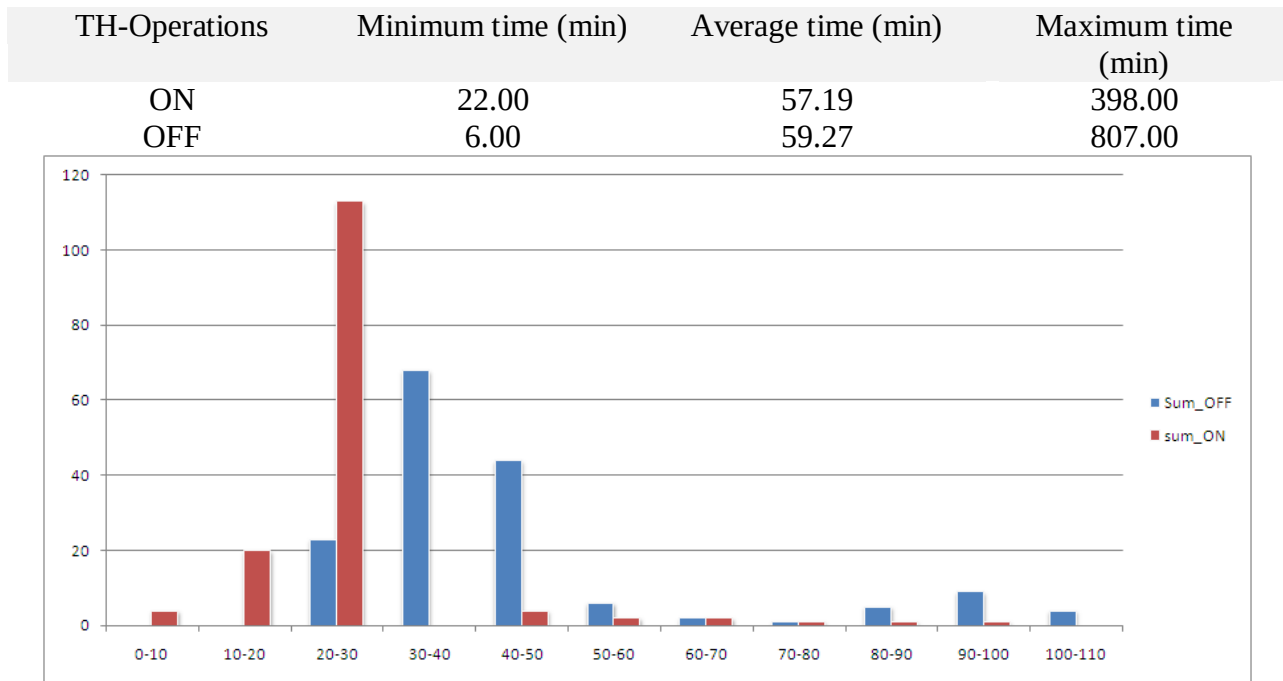


Figure 4. Operation intervals based on the traditional thermostat-control

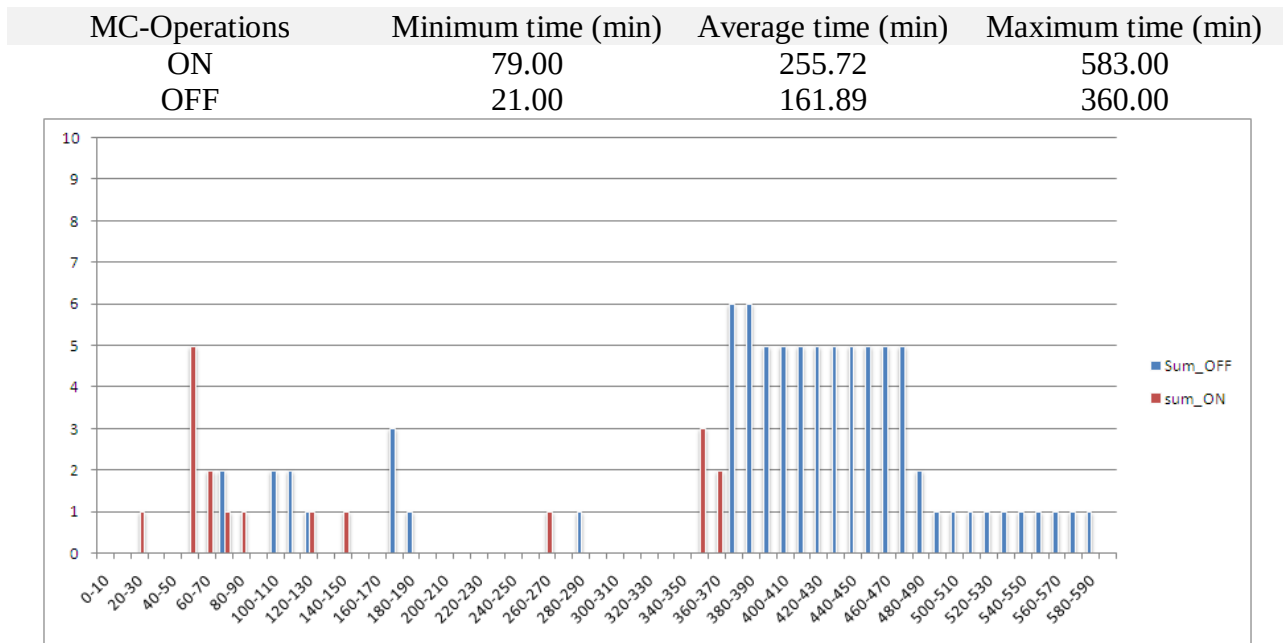


Figure 5. Operation intervals based on “The mina Concept”

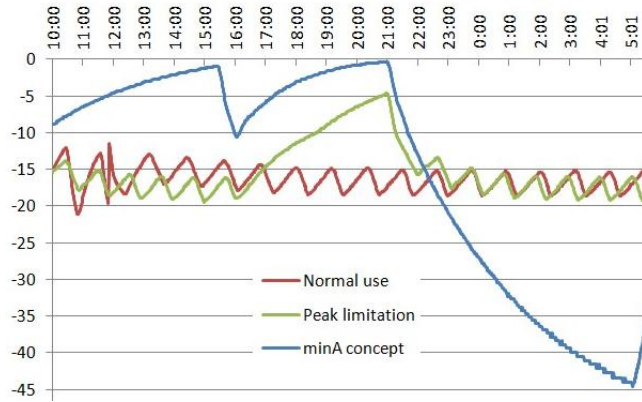


Figure 6. FRZ-AIR TH4

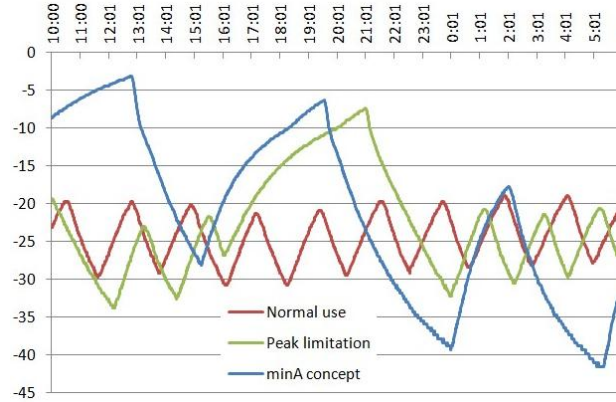


Figure 7. FRZ-AIR TH6

Based on the results of the test we can offer a possible grid friendly development of household refrigerators: a balance valve between the freezer and the refrigerator.

In this way we can solve the buffering task in 2 steps:

1st: Buffer the energy of renewable electricity sources using DSM control, or switch off the device when the electric system is overloaded (using various setpoints is possible not only with the refrigerators but all the other heat storage equipment as well, if the system operator has information about the actual conditions of the device)

2nd: Transmit the cold air from the freezer part to the refrigerator part when it is necessary

5 CONCLUSION

We considered the cooling demand (an electricity-driven service) of a domestic refrigerator in our wire-logistics as a special need that sometimes can be delayed – in „The minA Concept” we present an economically and technically achievable, environmentally sustainable way of cooling unit operations.

We introduced a new pathway in domestic refrigerator advancement based on our special wire-logistics approach – it is possible to not just disable, but to simply limit the operating conditions or use pre-cooling in the deep valley periods (before morning peak and uploading, etc). Limitation or disabling can be applicable in warehouses as well – the trucks with vegetables

usually arrive in the morning, unloading takes time, while the doors are open – it is possible not to start the refrigerator units for cooling the street, etc.

In the successful integration of renewable electricity sources it is possible to use demand side management control for matching renewable production and electricity-based cooling (RC, RCC, DSM) with

- having information about actual temperature of heat-storage equipment: thermoelectric sensor and information for the system operator
- improving the level of storage based on “The minA Concept”: using control tools instead of enabling and disabling

From the electric system operator point of view the application of “The minA Concept” as a tool has great promises (it is possible to use in the same way as night charge boilers and electrical heaters) – there is no need for special infrastructure, the electric network can transmit the “limitation” or “disabled” signal itself, only a cheap receiver-transmitter electronics in the refrigerator. The question remains: will the producers be opened for this type of innovations, and will people buy the required electronic equipment for centralized minA-control? Which type of tariff system can support these changes?

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