Information and Services to be Determined by Digital Twins

Technical milestone report (TMS 7.1) for work package 7 in the project

Digital twins for large-scale heat pumps and refrigeration systems

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Content

1. Purpose and background

In WP7 an analysis will be made regarding the potential for digital twins to create socioeconomic benefits. Digital twins enable various services, that can yield benefits to a variety of stakeholders. In order to best exploit these services, work package 7 will analyze and derive recommendations for optimally exploiting the potentials implied by digital twins for heat pumps and refrigeration (supermarket) systems.

To support work package 7, this TMS 7.1 report defines the baseline for information and services to be determined by digital twins by estimating which services that has the highest potentials for supermarket and heat pumps systems, respectively.

2. Supermarket systems value creation

Today most supermarkets are under a monitoring service that typically only reacts in case critical alarms appears that potentially otherwise can lead to food damage. The monitoring service provider will then go ahead and trigger an unscheduled service call to the store, providing the service engineer with no or little information on the fault and root cause.

In the supermarkets a vast amount of data points/sensor information are available and can be uploaded in the cloud. This enables the possibility to implement services/automation on top of the existing control and monitoring system to improve the performance mainly in following areas:

- Improved temperature quality
- Lower energy consumption/reduced CO_2 emissions
- Reduced maintenance cost

For the end-customers, i.e. the supermarket owners, these are the areas where an improved operation of the refrigeration system creates cost reductions in terms of reduced food loss and lower operation costs, while it also supports a green image.

The savings can be achieved through early identification of system inefficiencies and faults. The earlier these can be identified, the bigger the value (cost impact), as the effects on the operational cost can be reduced and even avoided if failures/inefficiencies can be predicted beforehand and proactive measures can be planned and executed.

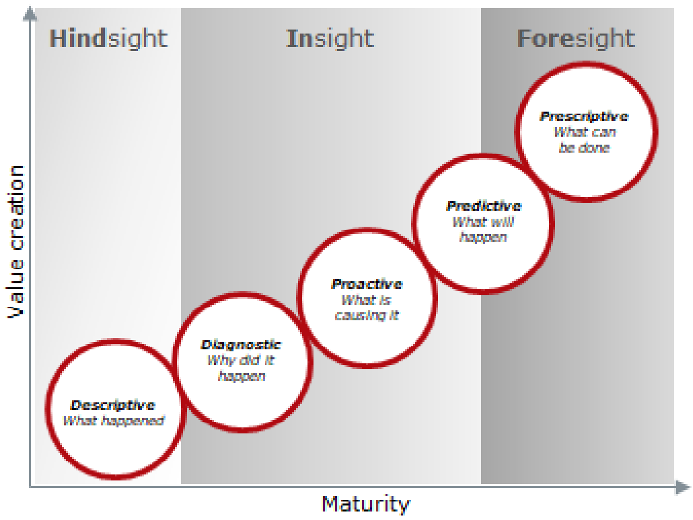

Figure 1: Value creation.

Figure 1 depicts the development "journey" (maturity) and the value creation – the earlier and more precise and actionable information that can be provided, the larger the value is for the end customers.

To attain these values, it is necessary to establish an algorithmic foundation, a "Digital Twin", that enables the detection/prediction of potential system efficiency deficits and failures. The figure below describes the value chain from the Digital Twin to the value is provided for the end customer.

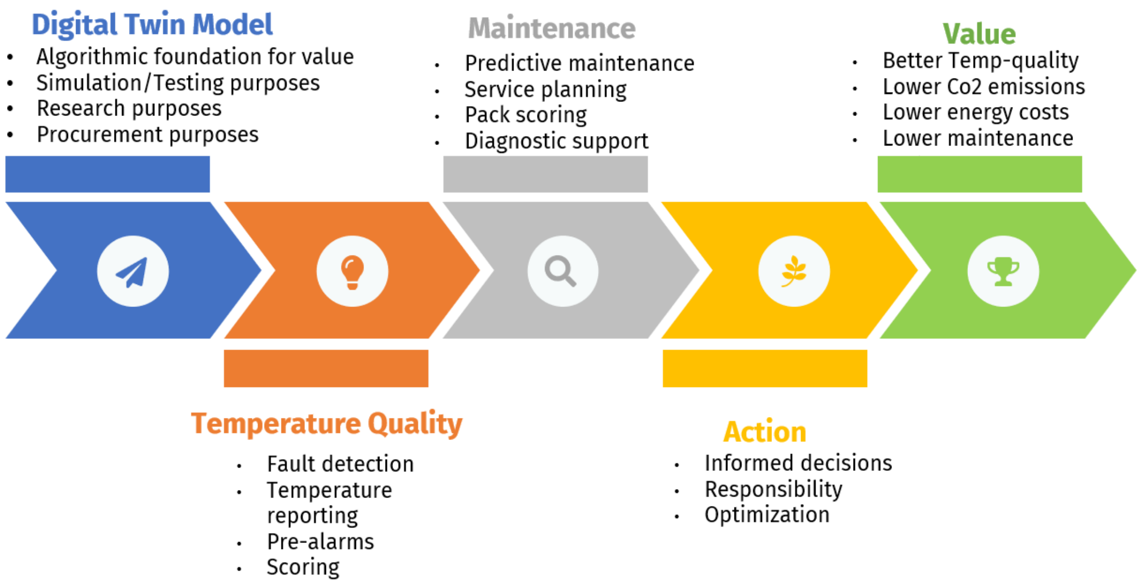

Figure 2: Value chain for Digital Twins to refrigeration systems.

The value is realized to the end-customer by providing more insightful monitoring services and scheduled preventive maintenance. Besides these benefits CO_2 emissions can be reduced by more efficient operation of the supermarkets refrigeration system which leads to lower energy consumption and food loss, which is estimated to have a significant social economic benefit.

Focus area

As part of the project a failure mode and effects analysis (FMEA) has been done and the most important failures has been identified i.e., the ones that have the highest frequency and severity. The top 5 failures are shown in Table 1. These faults will serve as the initial focus area for building up the supermarket digital twin.

Table 1: Top 5 failures – refrigeration systems

Fault mechanism	Frequency	Severity	Explanation/identification
Lack of refrigerant charge in the system	Medium	A	• Formation of flash gas at inlet to valve
Fan broken	Medium	B	• The fan stops operating (blocked of drive fault) • Can evolve over time, as one cabinet typically includes several fans, which may fail one after another
Wing bent	Medium	B	• Because of icing/physical damage a wing could be bent created a suboptimal air flow in the cabinet
Icing around evaporator	High	B	• Insufficient defrosting parameters • Ice is building up around the evaporator • Heat transfer decreases • Mass flow of air decreases due to lower cross section
Icing around evaporator	High	B	• Faulty heating element • Ice is building up around the evaporator • Heat transfer decreases • Mass flow of air decreases due to lower cross section

It is not possible to find hard evidence in terms of statistics on how often these faults appears but is based on the field experience from Superkøl that are proving the maintenance and field services to the supermarkets.

3. Heat pump systems

Then number of installations of large-scale heat pump systems is increasing rapidly, which is increasing the socioeconomic benefit that can be achieved by efficient operation and integration of heat pumps in the energy system. One way of increasing the efficient operation and integration of heat pumps is by using digital twins which opens for a variety of different services which overall is defined in three service categories:

- Advanced system monitoring: Performance benchmarking, soft sensors, installation error analysis.
- Fault detection and diagnosis: Fault mechanism monitoring incl. early-stage warning and predictive maintenance. Also includes model-based interpretation of system alerts.
- Optimized system operation: Continuous set-point tuning and scheduling of production and downtimes.

And overview of the services in relation to the heat pump environment is seen in Figure 3.

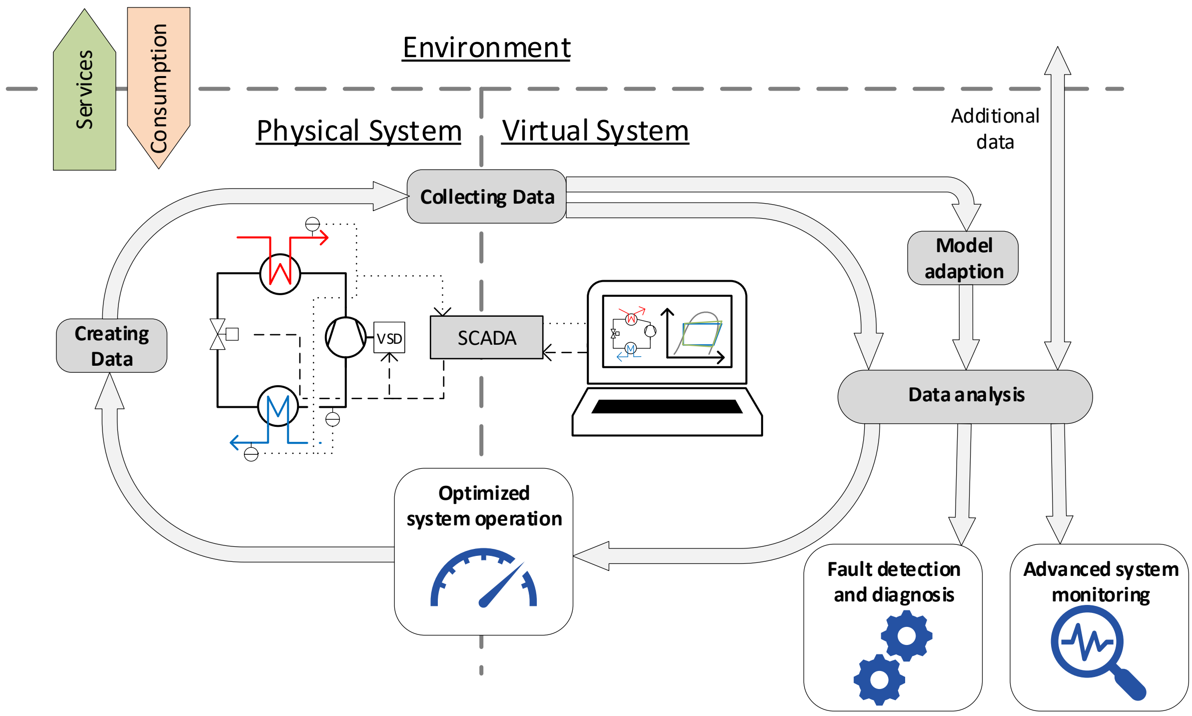

Figure 3: Heat pump services.

Each of these service categories can be further subdivided into different topics. An overview of all the identified categories and different topics can be found in Appendix A - "Largest potentials for HP systems". In order to further identify which services has the largest potential, and what will be the initial focus points when creating digital twins for large scale heat pump system, each of the topics has been ranked in the following three areas:

1. Effect, defined either according to fault detection and diagnosis (FDD) or optimized system operation/advanced system monitoring:
   - FDD: Multiplication of the estimated fault frequency and fault severity. For the estimated fault frequencies the paper "Operational challenges in large-scale ammonia heat pump systems" by Aguilera et. al. is primary considered. The definition used for the different levels of severities can be seen in Appendix A.
   - Optimized system operation/advanced system monitoring: Estimation made from very low to very high added value.
2. Advantage of using digital twin based services compared to current alternative (novel aspect): Estimation made from very low novel aspect for digital twin compared to current alternative.

3. Effort for implementing the digital based service (long term scope, not the R&D effort): Estimation made from very high to very low implementation effort regarding the availability for the digital twin framework to adjust to the operation of the existing systems.

Each of the areas are scored with points between 1-25 and summed to an overall relative potential. Description of the identified categories and topics, and further description of the ranking and scoring approach can be found in Appendix A. The top 10 with the estimated largest potentials for digital twin services to large-scale heat pump systems is shown in Table 2.

Table 2: Identification of largest potential for digital twin services to large-scale heat pump systems.

Service category	Topic	Overall relative potential* (high score = high potential)	Comment
Fault detection and diagnosis	Refrigerant leakage	55	Relative common fault. Can reduce risk of compressor break-down, give lower COP, and can have environmental implications.
Optimized system operation	Optimized set-point tuning	50	System can be operated with more optimal settings, hence optimal thermodynamic performance and energy efficiency can be improved by changing set points, in relation to changing boundary conditions e.g changes in price of eletricity, weather conditions, and compressor capacites. Also includes how to best integrate with thermal storage.
Advanced system monitoring	Performance benchmarking	47	Check if system lives up to promised performance from supplier (site acceptance test). E.g. is COP as expected at given conditions?
Fault detection and diagnosis	Heat exchanger fouling	45	Common fault in heat pump systems. Gives loss of efficiency, which is not critical on the short term, but leads to increased energy consumption over time (and lower COP).
Advanced system monitoring	Installation error analysis	35	Validity check for errors in installation.
Optimized system operation	Scheduling of production and downtimes	35	Can support energy management planning.
Optimized system operation	Flexible operation for supply of ancillary services	35	When is it favorable to let the heat pump perform flexible grid services? Includes forcast of electricity prices.
Optimized system operation	Operation according to electricity tariffs	35	Operation of heat pump with focus on electricity prices (and surplus of photovoltaics energy).
Fault detection and diagnosis	Excessive frosting in source HEX	34	The formation of frost on the surface of air-source HEXs can lead to a reduction of the performance and heating capacity of heat pump systems.
Fault detection and diagnosis	Condensation in suction line	34	Can occur with HPs operating under unstable conditions in the source and/or sink streams, or with fast changing set points (e.g during grid services).

The services in this top 10 is estimated to also have large socioeconomic potential, e.g. by increasing the energy efficiency with the use of advanced set-point tuning and by increasing the reliability of operation for the heat pump both leading to lower energy consumptions.

4. Conclusion

This milestone report builds onto the knowledge gained in the project with state-of-the-art reviews and overview of fault mechanisms for both heat pumps and supermarket systems. These experiences are in this report used for estimating which features and services the digital twin have the largest potentials, and hence will serve as the initial focus area for building up the digital twins in the project. The results are seen in Table 1 and Table 2, and summarized in Table 3 regarding the top 5 focus areas.

Table 3: Overview of initial focus area for building up the supermarket and heat pump digital twin.

Supermarket system	Heat pump system
Lack of refrigerant charge in the system	Fault detection and diagnosis: Refrigerant leakage
Fan broken	Optimized system operation: Optimized set-point tuning
Wing bent	Advanced system monitoring: Performance benchmarking
Icing around evaporator (insufficient defrosting)	Fault detection and diagnosis: Heat exchanger fouling
Icing around evaporator (faulty heating element)	Advanced system monitoring: Installation error analysis

The above services are in general estimated to generally have high potentials when looking broadly at all different types of system, for specific types of system there might be other services that have a larger potential.

For the supermarket system the identified services for the heat pump system are also relevant if heat recovery is made on the refrigeration system.