ETV Test Report
Danfoss AK-CC Controllers

DTI Refrigeration and Heat Pump Technology
J.no. 1001
Test no. 1 – Reduced energy consumption

Version 1.2

1. Table of contents

2. Introduction

Environmental technology verification (ETV) is an independent (third party) assessment of the performance of a technology or a product for a specified application, under defined conditions and quality assurance.

DANETV is a Danish center for verification of environmental technology.

This test report is the result of a test design developed for performance verification of an environmental technology following the ETV method.

2.1. Verification protocol reference

J.no 1001 – Danfoss - Verification Protocol

2.2. Name and contact of vendor

Danfoss A/S, Nordborgvej 81, 6430 Nordborg, Denmark
Contacts: Frede Schmidt (R&D Engineer) +45 7488 1553, e-mail: frs@danfoss.com
Peter Eriksen (R&D Director) +45 7488 4191, e-mail: peter_eriksen@danfoss.com

2.3. Name of centre/test responsible

Danish Technological Institute ,Verification Center, Refrigeration and Heat Pump Technology, building 14, Kongsvangs alle 29, DK-8000, Aarhus, Denmark.

Verification responsible:	Bjarke Paaske (BJPA), e-mail: bjarke.paaske@teknologisk.dk, Phone: +45 7220 2037
Internal reviewer:	Anders Mønsted (ANMD), e-mail: anders.monsted@teknologisk.dk, Phone: +45 7220 2273

2.4. Expert group

The expert group assigned to this verification and responsible for review of the verification plan and report documents includes:

Brian Elmegaard (BE), DTU, phone +45 4525 4169, e-mail be@mek.dtu.dk

3. Test design

The product test consists of two similar test-series showing the performance of a standard freezing cabinet. One test-series was carried out using predefined default settings on rail heat and defrost, and another series using adaptive rail heat and defrost. The effect of the adaptive functions in AK-CC controllers are verified, by comparing the results.

The performance test is based on the existing European Standard ISO 23953. ISO 23953 is the standard performance test for freezing cabinets, measuring both power consumption and cooling ability. It is important to notice that ISO 23953 is a performance test of the cabinet – not the controller. By comparing several performance tests of the cabinet using both default and adaptive settings, the effect of adaptive control will prove through the performance of the cabinet.

The targets of the product are:

- Optimized control of both rail heat and defrost
- Automatic adaptation of rail heat according to the current dew point temperature of the surrounding air.
- Frost formations are monitored and the system will only initiate defrost sessions when needed.

The effects of the product are:

- Reduced energy consumption – both directly at the heaters and indirectly at the cooling system.
- Reduced mean temperatures of the cooled products.

The test method is described in appendix 4 – In-house test methods.

3.1. Test site

The performance tests were carried out in a climate chamber at the Danish Technological Institute in Aarhus.

3.2. Type of site

The climate chamber used was previous accredited for performance tests according to ISO 23953. The accreditation expired in 2007 and has not been renewed since then, as ISO 23953 tests are now performed at another location.

The chamber is still equipped according to ISO 23953 and previous to testing, all equipment were checked using calibrated references.

3.3. Addresses

The address of the site is:
Danish Technological Institute, Building 14, Kongsvang Allé 29, 8000 Århus C.

3.4. Descriptions

AK-CC controllers are complete refrigeration appliance controllers for a great number of different refrigeration appliances and cold store rooms.

The controller is an electronic unit that controls the different functions of a cooling application. In applications with cooling and freezing cabinets the main functions of the controller are: liquid injection of refrigerant in the evaporators, monitoring of superheat, defrosting of evaporators, rail heat, control of compressors, control of night blinds and control of lights.

A single controller is able to operate up to four evaporators. Larger and more complex systems consist of several controllers managed through an overall system unit called a “system manager”. Danfoss system managers are able to monitor alarms and data logging of decentral refrigeration system. More System Managers can be applied by means of IP connections, in order to register measurements from up to 400 controllers. Remote operation is available through modem connection or an IP network.

AK-CC controllers hold adaptive functions of rail heat and defrost control. The necessity of both rail heat and defrost depends on the moisture levels of the ambient air. By adaptive adjustment the controller will provide rail heat and defrost according to a current demand and not excessively as conventional systems.

3.5. Tests

3.5.1. Test methods

The test method used is described in appendix 4 – In-house test methods.

3.5.2. Test staff

The test staff is:

Klaus Frederiksen	Sampling and reporting
Lasse Søe	Head of laboratory
Jesper Weinkauff Jakobsen	Sampling

3.5.3. Test schedule

Task	Timing
Application definition document	May 2009
Verification protocol with testplan	Oct. 2009
Test	Nov. 2009
Test reporting	Nov. 2009
Verification	Mar. 2010
Verification report	Apr. 2010
Verification statement	Apr. 2010

3.5.4. Test equipment

The test equipment includes:

- Refrigeration circuit
  - 2 pressure sensors for evaporation- and condensation pressure
  - 2 temperature sensors for liquid line temperature and suction superheat
  - Mass flow meter for refrigerant mass flow

- Cabinet
  - Arneg Brema 2 BT 1562 (Freezing cabinet)
  - Copeland Scroll R404A condensing unit
  - 3 power meters for rail heat, defrost and auxiliary
  - 54 M-packages (equipped with temperature sensors)
  - Additional test packages according to ISO 23953

- Climate chamber

- Temperature sensor for ambient air
- Humidity sensor for ambient air
- Air velocity sensor for ambient air

All data are collected via TI-DOP and Danfoss Cool-Tools (data collection software).

3.5.5. Operation conditions

During operation the controller uses the following settings:

- Temperatures
  - Cuttout -21,0° C
  - Diff. 2 K
  - Night setback 1 K
- Defrost
  - Min. time between def. 120 min
  - Max. defrost interval 24 h
  - Fan running during def "No"
  - Pump down delay 0 min
  - Drip delay 0 min
  - Fan delay 0 min
  - Fan start temp. -5° C
  - Max. hold time 20 min
- Rail heat
  - Rail ON at day 80 %
  - Rail ON at night 30 %
  - Dew point max. limit 22,3° C
  - Dew point min. limit 3,0° C
  - Rail heat min. ON % 10 %
  - Rail cycle time 6 min.
  - Rail during defrost Yes

Daytime is scheduled from 8:00 to 20:00 every day.
During run 1, 3, 5, 7 and 9 "Adaptive defrost" is set to "Not used" in the defrost menu. Defrost is scheduled at 6:00 and 19:00 every day. "Rail heat control" is set to "Timer".
During run 2, 4, 6, 8 and 10 "Adaptive defrost" is set to "Full adaptive" in the defrost menu. "Rail heat control" is set to "Dewpoint"

Factory settings are used for parameters not mentioned here.

3.5.6. Operation measurements

The system was operated under various conditions before the performance test to assure that everything was working correctly. Data collection from all measuring equipment was evaluated to check that the system was running as planned.

3.5.7. Test matrix

Testing was carried out according to the matrix below, meaning 5 samples of two runs each. Each sample uses different ambient conditions tested using both adaptive and default settings of the controller.

Energy consumption / temperature test					
Sample number	Run number	Settings			
		Control method	Temperature	RH Day / Night	Specific correction factor
01	01	Default	20° C	33 / 15 %	0,09
	02	Adaptive	20° C	33 / 15 %	
02	03	Default	20° C	41 / 24 %	0,17
	04	Adaptive	20º C	41 / 24 %	
03	05	Default	20° C	49 / 36 %	0,39
	06	Adaptive	20° C	49 / 36 %	
04	07	Default	20° C	59 / 52 %	0,23
	08	Adaptive	20° C	59 / 52 %	
05	09	Default	20° C	72 / 66 %	0,12
	10	Adaptive	20° C	72 / 66 %	

The specific correction factor is used when determining the total annual energy reduction (effect of the product). By correcting this way common ambient conditions are weighted higher than seldom occurring ambient conditions.

The methods described in appendix 4 (In-house test methods) and appendix 5 (In house data processing) was followed during the test.

3.5.8. Product maintenance

No maintenance is required for testing the product.

3.5.9. Health, safety and wastes

The use of this product does not imply special health, safety and waste issues. Work during testing will comply with the general rules regarding safety at DTI.

4. Reference analysis

4.1. Analytical laboratory

No external analytical laboratories were used for this verification process. All measuring and data processing were executed by the DTI test staff.

The test sub-body is responsible that:

- The performance test was carried out according to the test plan
- Data processing was carried out according to the methods described in the test plan
- Adequate internal reviews were performed on both test setup and data processing
- All procedures were carried out according to the Centre Quality Manual

4.2. Analytical parameters

The parameters processed to verify the effect of the product were:

- Electrical power consumption of refrigeration circuit is determined via:
  - Evaporation pressure
  - Condensation pressure
  - Temperature of refrigerant liquid supply
  - Temperature of refrigerant suction gas
  - Mass flow of refrigerant

- Electrical power consumption of defrost
  - Electrical power consumption is measured separately at the defrost heaters

- Electrical power consumption of rail heat
  - Electrical power consumption is measured separately at the rail heat system

- Electrical power consumption of auxiliary
  - Electrical power consumption is measured of auxiliary equipment

- Temperatures of M-packages
  - The temperature level of 54 M-packages

Furthermore the temperature and relative humidity of the ambient air in the climate chamber were logged throughout the tests in order to assure that conditions were stable during the entire test period.

4.3. Analytical methods

Data was processed according to the methods described in appendix 5 – In-house data processing.

4.4. Analytical performance requirements

A specially designed Excel spreadsheet and EES calculation file were used to calculate the performance from the measured parameters. As data were copied between several files, thorough reviews were performed as described in appendix 5.

5. Data management

5.1. Data storage, transfer and control

The data to be compiled and stored are summarized in table below. Analytical raw data were filed and archived according to the specifications of the quality management system.

Data type	Data media	Data recorder	Data recording time	Data storage
Test plan and report	Protected PDF-Files	Test responsible	When approved	Files and archives at TI
Log files	Excel and txt-files	Technician, TI	During collection	Files and archives at TI
Calculations	Excel and EES files	Test responsible	During calculation	Files and archives at TI
Final result and verification report	Protected PDF-files	Test responsible	After testing	Files and archives at TI

6. Quality assurance

6.1. Test plan review

Internal review of the test report was done by ANMD
External review of the test report is described in 1.4
Verification of this test report was performed by verification centre at DTI.

6.2. Performance control

The cabinet, condensing unit and controller was tested thoroughly before the verification tests were initiated. No malfunctioning was detected.

6.3. Test system control

Test and measuring equipment was checked against references or calibrated to ensure accurate values as described in appendix 4 – In-house test methods. This was done prior to testing and no intermediate check or calibration is necessary throughout the test period.

6.4. Data integrity check procedures

All transfer of data both handwritten and electronic, was subjected to 100 % control by another person.

Approved spread sheets and calculation programs for calculation of results was subjected to 100 % control to assure correct calculations and results.

Data input in spread sheets and calculation programmes was subjected to 100 % control, in order to secure correct calculations and results.

6.5. Test system audits

No audit was performed

6.6. Test report review

Internal review of the test report was done by ANMD.
External review of the test report was done by the expert stated in chapter 1.4.

7. Test results

The test data report will be included in the verification report as appendix 7, according to the DANETV Center Quality Manual.

7.1. Perfomance test summary

The effect verified in this process was a reduction of the electrical energy consumption by 15 % without raising the maximum or mean temperature of the cooled products. The effect is not regarded valid if the product causes an increase of water vapour condensation at the cabinet.

Operational data
Operation of freezing cabinet, controller (product), data logging system and climate chamber was checked during the verification process.

The freezing cabinet was not able to work properly at the most humid conditions. This problem is described further in section 7.4 below.

No malfunctioning of the Danfoss controller was detected in any of the test runs.

Measuring and data logging system was checked on a regular basis and no irregularities were detected in any of the test runs.

Measuring equipment regarding temperature and humidity of the climate chamber was checked between each test run and no errors were detected.
Logged data shows that the temperature was kept within ±1° C of the set point and relative humidity within ±5 units of the relative humidity percentage as required.
The air velocity in the climate chamber was checked manually between each run and no deviations were detected.

Energy consumption
Results of the performance test show reduced electrical energy consumption using the product in sample 1 – 4. Results from sample 5 are neglected because of ice blocking as described in section 7.4 below.

Temperature of the cooled products
Results of the performance test in sample 1 – 4 show that both mean and maximum temperature of the test packages were reduced using the product. Results from sample 5 are neglected because of ice blocking as described in section 7.4 below.

Water vapor condensation at the cabinet
Inspection of water vapor condensation showed no running water with the product applied. Running water was however present at run no. 7 using the default settings of rail heat.

7.2. Test measurement summary

The overall test results are summarised in the table below. Results from sample five are neglected because of improper functioning of the freezing cabinet. Because of this the results from sample five are not comparable to the results of the other samples. Energy and temperature reduction of sample five are regarded as 0, and have no influence of the overall result.

		Temperature [° C]		Energy	Results			Average	
Sample	Run no.	Package avg.	Package max	Total [kWh]	Temp. diff.	Energy red.	Factor	Temp. red.	Energy red.
1	1	-17,15	-11,44	29,1	-0,45	29 %	0,09	**-0,35**	**15,1 %**
	2	-17,60	-12,32	20,7					
2	3	-17,21	-11,25	29,2	-0,39	26 %	0,17		
	4	-17,61	-12,45	21,6					
3	5	-17,10	-10,90	30,1	-0,32	16 %	0,39		
	6	-17,42	-11,32	25,2					
4	7	-16,81	-9,64	31,6	-0,52	7 %	0,23		
	8	-17,33	-10,73	29,3					
5	9	-17,11	-10,36	30,6	0,00	0 %	0,12		
	10	-16,36	-9,22	33,3					

It is concluded for Danfoss AK-CC Controllers:

- Using the adaptive control method means an annual reduction in electrical energy consumption of 15,1 % of the display cabinet, for this type of application.
- Using the adaptive control method means an annual average temperature reduction of 0,35 K of the cooled products for this type of cabinet.
- Using the adaptive control method means reduced water vapor condensation for this type of cabinet (running water was only present in run 7).
- The result of the verification process is very dependent on the type of cabinet used as well as geographical location, default settings, opening hours etc. It is likely that the

adaptive control method will have a different influence on other types of cabinets in different applications.

7.3. Test quality assurance

The quality was assured according to the Centre Quality Manual and the procedures described in appendix 4 – In-house test methods and appendix 5 – In-house data processing.

7.4. Deviations from test plan

It was not possible to complete test runs 9 and 10, because of ice blocking in the cabinet.

The high humidity level means that a large amount of ice is created in the bottom of the cabinet. Defrost sessions melts ice at the evaporators but under these circumstances the water from defrost sessions, freezes at the bottom before exiting the cabinet. The ice formations reduce ventilation air at the evaporators and at some point the cooling capacity is inadequate to keep the temperature at the correct level.
The ice formations were removed and the test runs were repeated several times with the same result.

Because of this run no. 9 and 10 are not comparable with the other test runs, and results of these runs are not used for the verification process. Energy and temperature reduction at annual periods representing these runs are regarded as 0, when determining the overall annual effect.

According to experienced service technicians, the specific type of cabinet used for the performance test is known of having severe ice blocking problems in real installations during humid periods.

Appendix 1 Terms and definitions used in the verification protocol

Terms and definitions used in the protocol are explained in Table 1:

Table 1 - Terms and definitions used by the DANETV test centers

Word	**DANETV**	**Comments on the DANETV approach**
Analytical laboratory	Independent analytical laboratory used to analyse test samples	The test center may use an analytical laboratory as subcontractor
Application	The use of a product specified with respect to matrix, target, effect and limitations	The application must be defined with a precision that allows the user of a product verification to judge whether his needs are comparable to the verification conditions
DANETV	Danish center for verification of environmental technologies	None
(DANETV) test center	Preliminary name for the verification bodies in DANETV with a verification and a test sub-body	Name will be changed, when the final nomenclature in the EU ETV has been set.
Effect	The way the target is affected	The effect could be reduced energy consumption, better cooling performance etc.
(Environmental) product	Ready to market or prototype stage product, process, system or service based upon an environmental technology	The product is the item produced and sold and thus the item that a vendor submit for verification
Environmental technology	The practical application of knowledge in the environmental area	The term technology is covering a variety of products, processes, systems and services.
Evaluation	Evaluation of test data for a technology product for performance and data quality	None
Experts	Independent persons qualified on a technology in verification	These experts may be technical experts, QA experts for other ETV systems or regulatory experts

Word	DANETV	Comments on the DANETV approach
Matrix	The type of material that the product is intended for	Matrices could be cooling systems, cabinets, heat exchangers etc.
Method	Generic document that provides rules, guidelines or characteristics for tests or analysis	An in-house method may be used in the absence of a standard, if prepared in compliance with the format and contents required for standards.
Performance claim	The effects foreseen by the vendor on the target (s) in the matrix of intended use	None
Performance parameters	Parameters that can be documented quantitatively in tests and that provide the relevant information on the performance of an environmental technology product	The performance parameters must be established considering the application(s) of the product, the requirements of society (regulations), customers (needs) and vendor claims
Procedure	Detailed description of the use of a standard or a method within one body	The procedure specifies implementing a standard or a method in terms of e.g.: equipment used
Producer	The party producing the product	None
Standard	Generic document established by consensus and approved by a recognized standardization body that provides rules, guidelines or characteristics for tests or analysis	None
Target	The property that is affected by the product	Targets could be temperature [° C], energy [kWh] etc.
Test center, test sub-body	Sub-body of the test center that plans and performs test	None
Test center, verification sub-body	Sub-body of the test center that plans and performs the verification	None
Test/testing	Determination of the performance of a product for parameters defined	None

Word	**DANETV**	**Comments on the DANETV approach**
	for the application	
Vendor	The party delivering the product to the customer	Can be the producer
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance	None

Appendix 2 References (verification protocols, requirement documents, standards, methods)

1. DANETV. Center Quality Manual, 2008

2. European Parliament and Council. Directive 2006/42/EC of the 17th May 2006 on machinery and amending Directive 95/16/EC (recast).

3. European Council: Directive 89/655/EEC of 30 November 1989 concerning the minimum safety and health requirements for the use of work equipment by workers at work (amended 2007/30/EC).

4. ISO 12100-2:2003: Safety of machinery - Basic concepts, general principles for design - Part 2: Technical principles

5. European Standard EN ISO 23953 – Refrigerated display cabinets

6. Danish “Design reference year” DRY-data, 1995

7. ISO 13788 – Hygrothermal performance of building components and building elements (Internal humidity loads)

8. Measurement protocol for energy reductions in Refrigerated display cabinets for ETV tests at DANETV

Appendix 3 Application and performance parameter definitions

This appendix defines the application and the relevant performance parameters application as input for verification and test of an environmental technology following the DANETV method.

A3.1 Applications

A3.1.1 Matrix/matrices

- The matrix of the application is freezing/cooling cabinets in retail stores.

A3.1.2 Target(s)

- The target of the product is:
    - Optimized control of rail heat and defrost sessions
    - The power of the rail heat system will adapt according to the surrounding air temperature and humidity and keep the rail temperature a few degrees above the dew point at all time.
    - Frost formations are monitored and the system will only initiate defrost sessions when needed.

A3.1.3 Effects

- The effects claimed by the vendor are presented in table 2:

Table 2 - Performance parameters and vendor claims

Performance parameter	Vendor claim of performance
Reduction of energy consumption	15 % reduction of overall energy consumption
No increase in temperature of cooled products	Mean and maximum temperature of cooled are not increased as a side effect of the product
No increase in water vapor condensation	Water vapor condensation is not increased as a side effect of the product

Appendix 4 In-house test methods

Calibration programme
Before starting the tests it is secured that all measuring equipment complies with the accuracy specified by ISO 23953.
All sensors and meters is either calibrated or checked against calibrated equipment.

Set up
The cooling/freezing cabinet is set up and loaded according to ISO 23953. Measuring equipment is set up and correct data logging is secured before the tests are initiated.

Data collected via TI-DOP consist of:

- Time
- Temperature sensors from 54 M-packages
- Temperature and humidity of ambient conditions
- Refrigerant mass flow, temperature of refrigerant liquid line and temperature of refrigerant suction gas
- Power consumption of rail heat, defrost heaters and auxiliary (measured individually)

Data collected via TI-DOP are logged every 15 seconds.

Data collected via CoolTools consist of:

- Refrigerant pressure at liquid line and refrigerant pressure at the evaporators

Data collected via CoolTools are logged every 30 seconds.

Clocks on the TI-DOP logging system and Cool Tools logging system are synchronized as part of the set up.

The cabinet is loaded with M- and test-packages according to ISO 23953-2 chapter 5.3.2.3. It is secured that all used packages comply with the specifications given by ISO 23953-3 chapter 5.3.1.4. All packages are provided with a unique number in order to track the packages and match the logged temperature in TI-DOP to a specific M-package.

Parameters of the controller are set according to the values determined in agreement of the product supplier and the verification responsible. The parameters are found in chapter 3.5.5 of this test plan.

Proper function of cabinet, condensing unit, controller, climate chamber and data logging equipment is tested thoroughly before the performance tests are initiated.

After set up, the testing according to the matrix described in chapter 3.5.7 can begin. Each test run begins subsequent to a “running in” period as described below.

To avoid prolonging of the tests, it is important to complete the runs consecutive following the order given by the test matrix.

Running in

Prior to the test period a "running in" period is executed.

The running in period starts at 9:00 AM the day before the test run (day 1). This leaves 23 hours for the running in period, followed by a 24 hour test period from 8:00 AM (day 2) to 8:00 AM (day 3) the two consecutive mornings.

The specific ambient conditions and settings of the controller for the current sample are set just after 8:00 AM. At the same time data logging via TI-DOP is initiated, in order to compare temperatures and energy consumption of defrost sessions. Data logging of the pressures via CoolTools is not necessary during the running in period.
The specified ambient conditions must be present at 9:00 AM as the running in period starts.

Day time ambient conditions are used from 9:00 AM to 8:00 PM, and night time conditions are used from 8:00 PM to 8:00 AM the following morning. The settings of ambient conditions are changed at 8:00 PM and should be present and stable in the climate room within 1 hour.

Test

The 24 hour test period follows the 23 hour running in period. At 8:00 AM the settings are altered to day time settings. At 8:00 PM the settings are changed back to night time settings. Data logging via TI-DOP is simply continued from the running in period, meaning that only a single log file is used for both running in and test period (48 hours). It is assured that logging of pressures via CoolTools is initiated prior to the test period.

It is important to note that the AK-Controller has limited capacity of data storage. The storage capacity is checked prior to the test period and if necessary data is saved several times throughout the test period (e.g. every 8 hours). If the storage capacity is exceeded CoolTools will overwrite earliest collected data and replace by latest logs.

Water vapour condensation

During each of the 24 hour test periods the cabinet is visually inspected for water vapour condensation three times. First inspection is done at the start of the test period. Second inspection is done half way through the test, just before ambient conditions are switched to night time settings. Finally a third inspection is done at the end of the test period.

Formations of water vapour condensation will typically be strongest at certain points of a cabinet. The amount of water vapour condensation is always registered at the area of the cabinet with the highest concentration (critical area).

For this verification, water vapour condensation is acceptable to some extent. Water vapour condensation can be categorised as fog, droplets or running water. Formations of fog and droplets are acceptable during tests using the adaptive functions of the controller.

Running water is however not acceptable during runs 2, 4, 6, 8 and 10, unless the controller provides 100% rail heat. In this case the heaters of the cabinet (rather than the controller) are inadequate to keep the surface temperatures at an acceptable level.
Water vapour formations are registered in runs 1, 3, 5, 7 and 9 for comparison.

The results are inserted in the spreadsheet as described in appendix 5 – In-house data processing.

Stable conditions
At the end of the 24 hour test period (just after 8:00 AM, day 3), it is verified that stable conditions was reached prior to the test period. This is done by comparing defrost sessions and the temperature of each individual M-package at the last log from the running in period (7:59:45 AM day 2) to the temperature of the last log of the test period (7:59:45 AM day 3)

For run numbers 1, 3, 5, 7 and 9, stable conditions are reached when the temperature difference between the two registered temperatures of each M-package is less than 1K and the average temperature of all M-packages have not changed more than 0,5K.
At run numbers 2, 4, 6, 8 and 10, defrost sessions vary depending on demand. Because of this both temperature levels (as described above) and defrost sessions must be equivalent when comparing the running in period to the test run.

That stable conditions were reached, is checked via the prepared Excel spreadsheet. The procedure is described in appendix 5 – In-house data processing.

Defrost sessions are stable when the following parameters are met:

a) The number of defrost sessions in the running in period and the test run is identical.
b) The point in time when each defrost session begins may not deviate more than 30 minutes, when comparing equivalent defrost sessions at the running in period and the test run.

If stable conditions are reached as described above, measured data from the test run is valid for the verification process. If stable conditions are not reached a third 24h period is added. Data from the period is then compared to data from the second period and so on until stable conditions are reached.

At the end of each test run it is assured that the clocks of the two logging systems are synchronized. If one of the clocks deviates more than three seconds from the other, the clocks are synchronized and the test is restarted.

Appendix 5 In-house data processing

Data processing
All data is processed via a basic excel spreadsheet and a basic EES calculation file prepared in advance. Copies of the basic Excel spreadsheet and the basic EES calculation file are created for each test run, meaning that data of a specific test run is processed in a spreadsheet/calculation file regarding the specific run only. The Excel spreadsheet of a specific run is named “ETV AK-CC – Run XX – Spreadsheet” and the EES calculation file of a specific run is named “ETV AK-CC – Run XX – EES Calculation” (XX being the number of the specific run).

The procedure is described below and visualised in figure 1 at the end of this appendix.

Results of the visual water vapour inspection are reported in the Excel spreadsheet of the specific run, sheet 5 “Results”, column I, row 17 – 19.

Before all data is processed, it is confirmed that stable conditions was reached prior to the test period. At the end of a test run just after 8:00 AM a log file from TI-DOP is saved, while the data logging system keeps running. The data file is opened via Microsoft Excel and the number of defrost sessions and point in time of each defrost session is compared for the running in period and the test period manually. If the defrost sessions corresponds to the definition of “stable conditions” as described in appendix 4 – In-house test methods, an “OK” is inserted in the spreadsheet, sheet 5 “Results”, column F, row 59.

TI-DOP files
Output files from the TI-DOP logging system are in txt file format. The data file of a specific run is opened via Microsoft Excel and saved in xlsx file format before any processing. The saved file is named “ETV AK-CC – Run XX – Processed data – TI DOP” (XX being the number of the specific run). The Excel file is then processed as follows:

Any columns with data other than that specified in “Set up” above are deleted.

Secure that the order of the columns is the same as the columns of the red input cells in the basic Excel spreadsheet, sheet 1 “Data from TI-DOP log”, columns A and D-BM (Column A is time, column D is massflow and so forth).

The top row indicates the data of each column. The second row should be the last log of the running in period (the log closest to 7:59:45 AM, day 2). Any rows holding data from logs before this point in time are deleted.

The bottom row should be the last log of the test run period (the log closest to 7:59:45 AM, day 3). Any rows holding data from logs later than this point in time are deleted.

The deleted rows and columns should leave a spreadsheet holding columns A-BK with a total number of rows of 5762, including the designation (top row) of each column.

The processed Excel file is now saved but not closed.

The spreadsheet of the corresponding run is now opened. Data from the processed Excel file (Hereinafter called “1”) is now copied to the spreadsheet (hereinafter called “2”), sheet 1 “Data from TI-DOP log”:

- Cell A2 in “1” is copied to Cell A2 in “2”.
- Cells B2 to BK2 in “1” are copied to cells D2 to BM2 in “2”
- Cells A3 to A5762 in “1” are copied to cells A4 to A5763 in “2”
- Cells B3 to BK5762 in “1” are copied to cells D4 to BM5763 in “2”

“1” is closed.

In “2” sheet 5 “Results” is selected. Stable conditions regarding temperature levels are now confirmed. If stable conditions were reached cells F4 to F58 all returns the value “OK”. If any of the cells return the value “False”, stable conditions have not been reached and no further data processing is needed.

If stable conditions have not been reached the test run is prolonged for another 24h period as described in appendix 4 – In-house test methods. The current spreadsheet is deleted and a new one is created as data from the next test run is available.

If stable conditions have been reached the spreadsheet is saved and closed. Data processing is continued as described below.

CoolTools files
Output files from the CoolTools logging system are in csv file format. Data collection via CoolTools will often consist of several log files due to the controllers limited memory for data storage. The first data file of a specific run is opened via Microsoft Excel and saved in xlsx file format before any processing. The saved file is named “ETV AK-CC – Run XX – Processed data – CoolTools” (XX being the number of the specific run). The Excel file is then processed as follows:

Secure that the order of the columns is the same as the columns of the red input cells in the basic Excel spreadsheet, sheet 2 “Data from Cool Tools log”, columns A, B and C (Column A is time, column B is evaporation temperature and column C is condensation temperature).

The top row indicates the data of each column. The second row should be the first log of the test period (8:00:00 AM, day 2). Any rows holding data from logs before this point in time are deleted.

If several log files exist, the next log file is opened and data is copied into the created Excel file holding data from the first log file. Data from the different log files are unified in the Excel file, so that the total number of rows holds data for every 30 seconds throughout the test run.

The bottom row should be the last log of the test run period (7:59:30 AM, day 3). Any rows holding data from logs later than this point in time are deleted.

The deleted rows and columns should leave a spreadsheet holding columns A-C with a total number of rows of 2881, including the designation (top row) of each column.

The processed Excel file is now saved but not closed.

The spreadsheet of the corresponding run is now opened. Data from the processed Excel file (Hereinafter called “3”) is copied to the spreadsheet (hereinafter called “2”), sheet 2 “Data from Cool Tools log”:

- Cells A2 to C2881 in “3” are copied to Cells A3 to C2882 in “2”.

Spreadsheet “2” is saved and “1” is closed.

Spreadsheet files
The spreadsheet combines the collected data of TI-DOP and CoolTools, and returns the values used for calculation of the heat extraction rate of the refrigerant. The values are available in the green output cells of the spreadsheet, sheet 3 “Data for EES calculation”, cells C2 to G5761.

Note that the Excel spreadsheet, sheet 3, calculates intermediate values of each pair of consecutive pressure values collected via CoolTools. Because of limited storage capacity using CoolTools, the values of pressure are only collected every 30 seconds and the intermediate values are calculated to match the data collected via TI-DOP every 15 seconds.

Columns A and B compare the log time of TI-DOP and CoolTools. It is secured that the log time between TI-DOP and CoolTools does not deviate more than 7 seconds in row 2 and row 5761.

EES Calculation files
Calculation of the heat extraction rate during a specific run is carried out using the copied EES Calculation file for the specific run.

Open the specific EES Calculation file (hereinafter called “4”) and select the “Lookup table”.

Data from the open Excel spreadsheet (“2”), sheet 3 “Data for EES calculation”, cells C2 to G5761 are copied to the lookup table in “4”.

“Parametric table” is selected in “4” and the calculation is initiated by pressing the green “play” – button in the top left corner. EES now calculates the instant cooling throughout the period.

The calculated values are copied from “4” row 2 “$Q_{cooling}$” of the Parametric table, and inserted in “2”, sheet 4 “Results power consumption”, cells D3 to D5762.

The EES Calculation file is saved and closed.

Final result
The calculated results of a specific run are collected in the Excel spreadsheet, sheet 5 “Results” of the specific run.

Results of each run are finally collected in another Excel spreadsheet named “ETV AK-CC – Final Result Energy Savings” (hereinafter called “5”).

Values from the green output cells in “2”, sheet 5 “Results” are copied to the red input cells of “5” sheet 1 as follows:

- Cells D4 and E3 in “2” are copied to columns F and G in “5”. The specific row depends on the run number
- Cells I3 to I7 in “2” are copied to columns H to L in “5”. The specific row depends on the run number
- Cells I11, I13 and I14 in “2” are copied to columns C to E in “5”. The specific row depends on the run number

If any running water was observed during the water vapour inspections (listed as R in cells I17 to I19 of “2”), an X is inserted in column M in “5”.

The total annual energy reduction is returned in cell Q3 of “5” and the average annual temperature reduction of the M-packages is returned in cell R3 of “5”.

Quality assurance
The processing procedure described above is repeated independently once by the test sub-body and once by the internal reviewer. This provides three independent results that are matched in order to secure correct results.

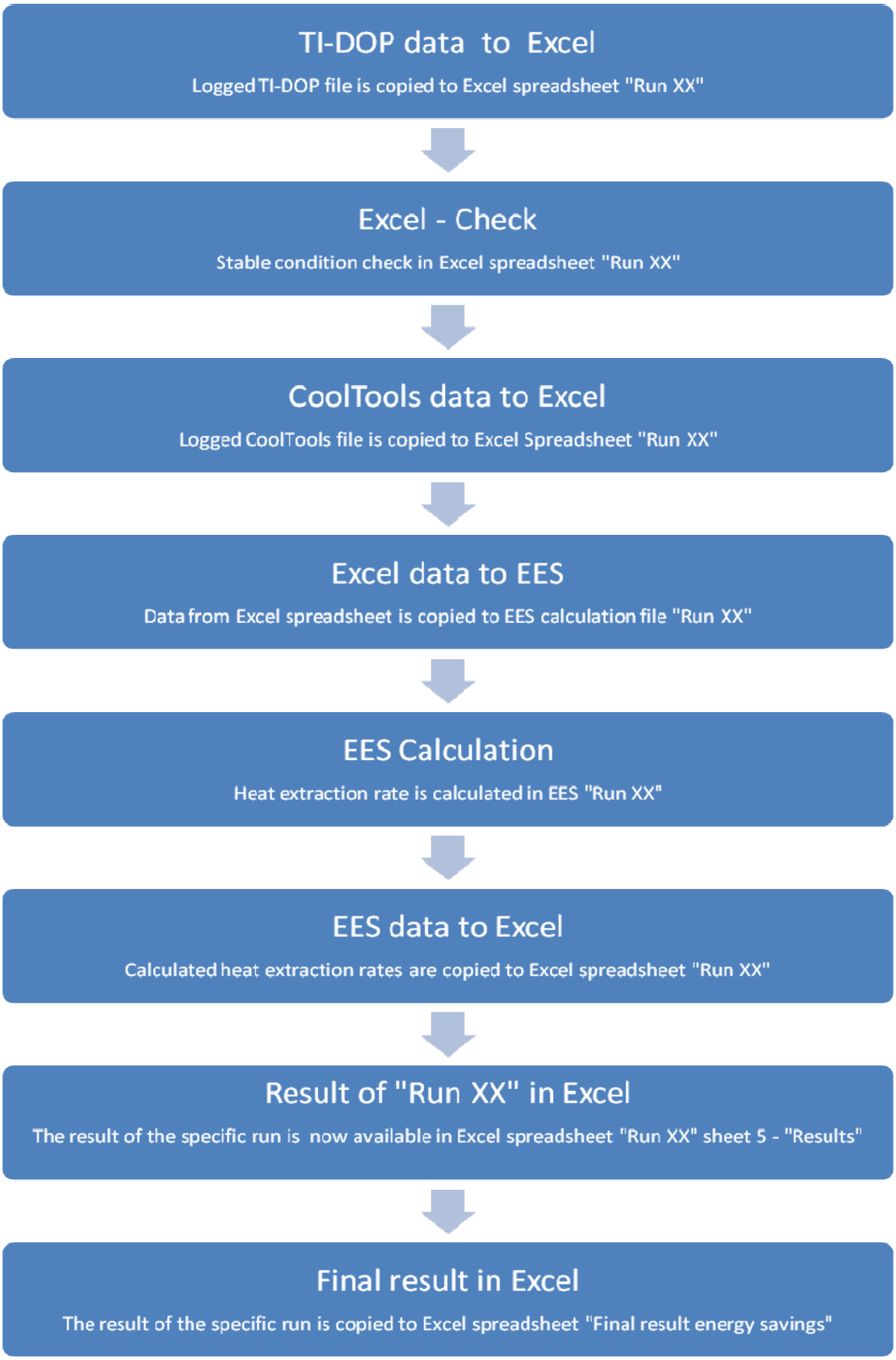

Figure 1 – Data processing steps

Appendix 6 Data reporting forms

All data are reported in the prepared Excel spreadsheets and EES Calculation files, as described above. Results are collected and commented in the test report.

Appendix 7 Test data report

Test

The test was performed as described in the test plan apart from the deviations described in chapter 7.4 of the test report.

Operational data
Ambient conditions during the test runs are shown in figure 7.1 below.

Sample no.	Run no.	Ambient conditions		
		Temp. avg.	Day RH avg.	Night RH avg.
1	1	19,6	33,1	29,9
	2	19,6	32,9	30,8
2	3	19,7	40,5	32,5
	4	19,6	40,5	30,2
3	5	19,9	49,0	35,9
	6	19,9	49,0	35,5
4	7	20,3	59,4	52,4
	8	20,2	59,4	52,4
5	9	20,5	71,8	66,4
	10	20,7	71,8	66,4

Figure 7.1 - Average ambient conditions during the test runs.

Following the test matrix, relative humidity ratios during night time settings of sample 1 and 2 should have been lower. It was not possible to reach these low levels of humidity in the climate chamber used and the test runs were executed with the lowest humidity possible.
The result of the verification however is not affected by the higher humidity ratios in sample 1 and 2. A lower humidity ratio would have increased the effect of the product and result in a verification of the effect by a larger margin.

The temperature in the climate chamber is slightly higher during the last test runs, than during the first. This has no influence, as the temperature only differs very little between the two runs of each sample.

All temperatures and relative humidity ratios (except during night time settings of sample 1 and 2) are within the tolerances specified.

Analysis results

Reduction of electrical energy consumption

The electrical energy consumption of the cabinet in each of the 24h test periods is shown in table 7.2 below.

		Energy consumption [kWh]						Results		
Sample	Run no.	Rail	Def.	Aux	Ref.	Total	Diff.	Energy red.	Factor	Overall
1	1	7,6	1,6	2,0	18,0	29,1	-8,4	29%	0,09	15,1%
	2	2,2	0,9	2,0	15,6	20,7				
2	3	7,6	1,6	2,0	18,0	29,2	-7,6	26%	0,17	
	4	3,0	0,9	2,0	15,7	21,6				
3	5	7,6	1,7	2,0	18,9	30,1	-4,9	16%	0,39	
	6	4,8	1,0	2,0	17,4	25,2				
4	7	7,5	1,8	1,9	20,4	31,6	-2,3	7%	0,23	
	8	7,5	1,1	2,0	18,7	29,3				
5	9	7,6	1,7	2,0	19,3	30,6	2,6	0%	0,12	
	10	10,1	1,0	2,0	20,2	33,3				

Figure 7.2 – Electrical energy consumption during the test runs.

As mentioned earlier the results of sample 5 are neglected due to large amounts of ice formation.

Electrical energy consumption is measured individually for rail heat, defrost, auxiliary (primarily fans) and the refrigeration system. The total electrical energy consumption of run no. 1 is 29,1 kWh. The total of run 2 is 20,7 kWh and the difference is a reduction of 8,4 kWh.
The electrical energy consumption of the refrigeration system is not measured directly, but determined from the cooling capacity using the method from ISO 23953 as explained in chapter 7.1 of the verification protocol.

As expected, the reduction of electrical energy consumption is higher during low humidity ratios. The reduction is primarily caused by lower demand of rail heat and defrost sessions.

Sample 1-4 covers 88 % of the annual hours and the average reduction during this period is 17,1 %. As the energy reduction is regarded as 0 during the last 12 % of the annual hours, the overall annual energy reduction is determined to 15,1 %.

Reduced temperature of the cooled products
The temperature levels of the measuring packages are shown in table 7.3 below.

Sample	Run no.	Temperature [° C]		Results			
		Package avg.	Package max	Water vapor	Temp. diff. [K]	Factor	Overall [K]
1	1	-17,15	-11,44		-0,45	0,09	-0,35
	2	-17,60	-12,32				
2	3	-17,21	-11,25		-0,39	0,17	
	4	-17,61	-12,45				
3	5	-17,10	-10,90		-0,32	0,39	
	6	-17,42	-11,32				
4	7	-16,81	-9,64	X	-0,52	0,23	
	8	-17,33	-10,73				
5	9	-17,11	-10,36	X	0,00	0,12	
	10	-16,36	-9,22				

Figure 7.3 – Temperature levels of test packages during the test runs.

As mentioned earlier the results of sample 5 are neglected due to large amounts of ice formation.

Temperature levels are measured individually on each of the 54 measuring packages. The column “Package avg.” in the table, shows the average temperature of all measuring packages during each of the 24h test runs. The column “Package max” shows the maximum temperature reached in any measuring package.
Both average and maximum temperatures are reduced using the adaptive functions.

Sample 1-4 covers 88 % of the annual hours and the average reduction during this period is 0,4 K. As the temperature reduction is regarded as 0 during the last 12 % of the annual hours, the overall average temperature reduction is determined to 0,35 K.

Running water caused by water vapour condensation was present in runs 7 and 9. No water vapour problems were detected using the adaptive functions.

Discussion and Conclusion

The following points are important to notice considering the effect of this product in real life applications:

- The effect of the product was only verified using a single type of cabinet
    - It is expected that other cabinets are effected different by the product
- Type of super market, default settings, opening hours, behaviour etc.
    - The test matrix is based on small size supermarkets with a lot of opening hours (11 hours a day – 7 days a week), which is a typical installation of this type of cabinet
    - The default settings used, are typical for this type of cabinet but may vary dependent on the installer, behaviour etc.
    - Door openings and load of products are based on ISO 23953, but may vary dependent on store, type of product, behaviour etc.
- The ambient conditions in the test matrix are based on stores without air conditioning or special air handling units
    - The result obtained in this verification process is not expected to be comparable for cabinets placed in special environments (for instance next to humidification systems for groceries etc.)

With the above in mind, it is concluded that the performance of adaptive functions for the Danfoss AK-CC Controllers is verified through performance tests on a specific freezing cabinet. The performance tests show reduced energy consumption as well as temperature levels of the products:

- The overall electrical energy consumption of the freezing cabinet is reduced by 15 % annually using the adaptive functions
- The overall annual average temperature levels of the products are reduced 0,35 K without increasing the maximum temperature present at any time
- No problems regarding water vapour condensation was detected – water vapour condensation was reduced at high humidity levels compared to tradition control method