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(54) A METHOD FOR GENERATING EARLY TEMPERATURE WARNING IN A VAPOUR COMPRESSION SYSTEM

(57) A method for operating a vapour compression system (1) is disclosed. A cut-in temperature, a high temperature alarm limit and a high temperature alarm delay time are set. A maximum acceptable relative decay value is derived, based on the high temperature alarm limit and the high temperature alarm delay time. The vapour compression system (1) is operated while monitoring a temperature inside a refrigerated volume and continuously deriving a weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length. In the case that the weighted mean temperature inside the refrigerated volume exceeds the cut-in temperature, a timer is started, and a delay time is derived, based on the weighted mean temperature and the maximum acceptable relative decay value. A warning is generated when the timer reaches the derived delay time.

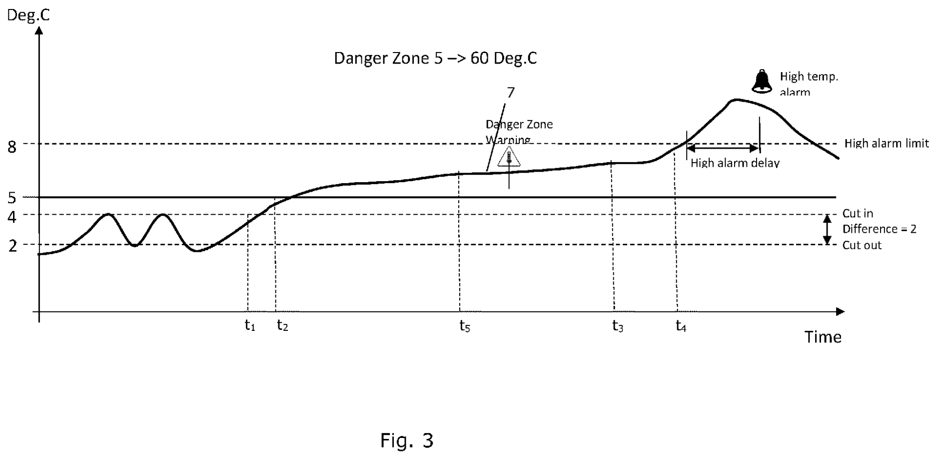

Fig. 3

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for operating a vapour compression system, the vapour compression system comprising at least one evaporator, each evaporator being arranged in thermal contact with a refrigerated volume for storing goods. The method according to the invention allows an early warning to be generated in the case that the temperature inside a refrigerated volume is above a specified level.

BACKGROUND OF THE INVENTION

[0002] Vapour compression systems may be used for providing cooling to refrigerated volumes or compartments, e.g. in the form of display cases in supermarkets or the like. Such refrigerated volumes may be used for accommodating goods which need to be stored at specified low temperatures, e.g. food products, drugs, etc. To this end, one or more evaporators of the vapour compression system are arranged in thermal contact with the refrigerated volumes.

[0003] For instance, fresh food products may be subject to bacterial growth, in particular if the food products are stored at temperatures between 5°C and 60°C, sometimes referred to as the 'temperature danger zone'. Therefore, it is normally required that fresh food products are stored at temperatures below 5°C. It may, however, be acceptable that food products are stored, for a limited time, at temperatures above 5°C. How much the temperature may be allowed to deviate from the specified storage temperature, and for how long, depends on the kind of goods being stored, in particular on the temperature sensitivity of the goods.

[0004] Accordingly, vapour compression systems are normally controlled by controlling the refrigerant supply to the evaporators in such a manner that the temperature inside the refrigerated volumes are maintained within a specified temperature interval below 5°C. More specifically, when the temperature inside a refrigerated volume reaches a specified cut-in temperature, an expansion valve associated therewith is opened, thereby providing a supply of refrigerant to the corresponding evaporator. This will cause the temperature inside the refrigerated volume to decrease. The expansion valve is kept open until a cut-out temperature is reached. Then the expansion valve is closed, thereby preventing that the refrigerant is supplied to the evaporator. This will cause the temperature inside the refrigerated volume to increase, and this is allowed to continue until the cut-in temperature is once again reached. Thereby it is ensured that the temperature inside the refrigerated volume is maintained substantially within the temperature interval between the cut-out temperature and the cut-in temperature, possibly with minor undershoots and/or overshoots.

[0005] In the case that the vapour compression system malfunctions or, for some reason, is not operating in an optimal manner, it may be difficult to maintain the temperature inside the refrigerated volume within the specified temperature interval. For instance, it may not be possible to drive the temperature down below the cut-in temperature, even if the expansion valve is kept fully open, and the temperature inside the refrigerated volume may even continue to increase. In order to prevent that the temperature inside the refrigerated volume increases to an unacceptable level, a high temperature alarm is normally generated if the temperature inside the refrigerated volume has increased to a specified elevated temperature level, e.g. 8°C, and has remained above this temperature level for a specified period of time, e.g. approximately 30 minutes. When such an alarm is generated, it will normally be necessary to attend to the matter immediately, in order to prevent or limit degradation of the goods stored in the refrigerated volume.

[0006] In some cases, the vapour compression system may be able to keep the temperature inside the refrigerated volume below the temperature which triggers the high temperature alarm, but not below the upper limit of the specified temperature range. In this case, a high temperature alarm will not be generated, even though the temperature inside the refrigerated volume is in reality too high. Accordingly, the goods accommodated in the refrigerated volume are stored at a too high temperature, potentially during a long time period. This may cause faster degradation of the goods, and possibly result in more goods than necessary being discarded.

DESCRIPTION OF THE INVENTION

[0007] It is an object of embodiments of the invention to provide a method for operating a vapour compression system, in which the risk of storing goods at elevated temperatures is decreased.

[0008] It is a further object of embodiments of the invention to provide a method for operating a vapour compression system which allows early detection of potential faults in the vapour compression system.

[0009] The invention provides a method for operating a vapour compression system, the vapour compression system comprising a compressor unit, a heat rejecting heat exchanger, at least one expansion device and at least one evaporator arranged in a refrigerant path, each evaporator being arranged in thermal contact with a refrigerated volume for storing goods, the method comprising the steps of, for at least one of the refrigerated volumes:

- setting control parameters related to the refrigerated volume, including setting a cut-in temperature, a high temperature alarm limit and a high temperature alarm delay time,
- deriving a maximum acceptable relative decay value, based on the high temperature alarm limit and the high temperature alarm delay time,
- operating the vapour compression system while monitoring a temperature inside the refrigerated volume and continuously deriving a weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length,
- in the case that the weighted mean temperature inside the refrigerated volume exceeds the cut-in temperature, starting a timer and continuing to derive the weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length,
- deriving a delay time, based on the weighted mean temperature and the maximum acceptable relative decay value, and
- generating a warning when the timer reaches the derived delay time.

[0010] Thus, the method according to the invention is a method for operating a vapour compression system. In the present context the term 'vapour compression system' should be interpreted to mean system in which a flow of fluid medium, such as refrigerant, circulates and is alternatingly compressed and expanded, thereby providing either refrigeration or heating of a volume. Thus, the vapour compression system may be a refrigeration system, an air condition system, a heat pump, etc.

[0011] In the present context the term 'operating a vapour compression system' should be interpreted to mean operating various components of the vapour compression system in order to provide the required cooling in the refrigerated volumes, while measuring or monitoring relevant parameters, and ensuring that various parts of the vapour compression system are performing as expected. It is noted that the method according to the invention is primarily related to monitoring of the vapour compression system with the purpose of ensuring that the vapour compression system operates appropriately and as expected.

[0012] The vapour compression system comprises a compressor unit, a heat rejecting heat exchanger, at least one expansion device and at least one evaporator arranged in a refrigerant path. Thus, refrigerant flowing in the refrigerant path is compressed by one or more compressors of the compressor unit, before being supplied to the heat rejecting heat exchanger. When the refrigerant passes through the heat rejecting heat exchanger, heat exchange takes place between the refrigerant and the ambient or a secondary fluid flow across the heat rejecting heat exchanger, in such a manner that heat is rejected from the refrigerant. The heat rejecting heat exchanger may be in the form of a condenser, in which case the refrigerant is at least partly condensed when passing through the heat rejecting heat exchanger. As an alternative, the heat rejecting heat exchanger may be in the form of a gas cooler, in which case the refrigerant passing through the heat rejecting heat exchanger is cooled, but remains in a gaseous or trans-critical state.

[0013] The refrigerant leaving the heat rejecting heat exchanger is supplied to the expansion device(s), where it is expanded before being supplied to respective evaporator(s). The refrigerant supplied to the evaporator(s) is in a mixed state of gaseous and liquid refrigerant. In the evaporator(s), the liquid part of the refrigerant is at least partly evaporated, while heat exchange takes place between the refrigerant and the ambient or a secondary fluid flow across the respective evaporator, in such a manner that heat is absorbed by the refrigerant. Finally, the refrigerant leaving the evaporator(s) is supplied to the main compressor(s).

[0014] Each evaporator is arranged in thermal contact with a refrigerated volume for storing goods. Thereby, due to the heat exchange taking place when the refrigerant passes through an evaporator, cooling is provided to the corresponding refrigerated volume.

[0015] In the method according to the invention, for at least one of the refrigerated volumes, control parameters for the refrigerated volume are initially set. This includes setting a cut-in temperature, a high temperature alarm limit and a high temperature alarm delay time.

[0016] In the present context, the term 'cut-in temperature' should be interpreted to mean a temperature value which triggers opening of the expansion valve which supplies refrigerant to the evaporator being arranged in thermal contact with the refrigerated volume. Thus, when the temperature inside the refrigerated volume reaches the cut-in temperature, then the expansion device is opened, thereby allowing a supply of refrigerant to the evaporator, and causing a decrease in the temperature inside the refrigerated volume. Thus, by setting the cut-in temperature it is determined at which temperature level the expansion valve should be opened for that particular refrigerated volume.

[0017] As alternative, the expansion device may be a modulating thermostat. In this case, the temperature inside the refrigerated volume is controlled according to a reference temperature, e.g. by means of a PI controller. The reference temperature is, in this case, typically in the middle of a temperature interval between a cut-out temperature and the cut-in temperature. The cut-in temperature still represents a temperature limit which it is undesirable that the temperature inside the refrigerated volume exceeds.

[0018] In the present context the term 'high temperature alarm limit' should be interpreted to mean a temperature level which triggers that a high temperature alarm is generated. The high temperature alarm limit is typically somewhat higher than the cut-in temperature, since it should be selected in such a manner that a high temperature alarm is only generated if it is certain that an elevated temperature which needs attention is prevailing inside the refrigerated volume. Thus, by setting the high temperature alarm limit it is determined to which extent the temperature inside the refrigerated volume can be allowed to exceed the upper boundary of the normally acceptable temperature interval. In other words, the high temperature alarm limit defines the highest acceptable temperature inside the refrigerated volume.

[0019] In the present context the term 'high temperature alarm delay time' should be interpreted to mean a time period which elapses from the temperature inside the refrigerated volume exceeds the high temperature alarm limit until a high temperature alarm is generated. It may be considered acceptable that the temperature inside the refrigerated volume exceeds the high temperature alarm limit very briefly, and therefore a high temperature alarm may only be generated if the temperature inside the refrigerated volume remains above the high temperature alarm limit for some time. Thereby it is ensured that a high temperature alarm is only generated if it is certain that an elevated temperature is prevailing inside the refrigerated volume, that the vapour compression system is not able to decrease the temperature, and that attention is therefore required. Thus, by setting the high temperature alarm delay time it is determined for how long it can be accepted that the temperature inside the refrigerated volume is above the high temperature alarm limit.

[0020] Thus, the control parameters being set all represent threshold values which are applied when operating the vapour compression system, and they may advantageously be set when the vapour compression system is installed. When setting the control parameters, the kind of goods to be stored in the refrigerated volume may be taken into account. For instance, for very temperature sensitive goods, a low high temperature alarm limit and/or a short high temperature alarm delay time may be selected, whereas a higher high temperature alarm limit and/or a longer high temperature alarm delay time may be selected for goods which are less temperature sensitive.

[0021] It should be noted that the cut-in temperature, the high temperature alarm limit and the high temperature alarm delay time are control parameters which are commonly set in prior art vapour compression system. Accordingly, the method according to the invention relies partly on control parameters which are already applied for other purposes, and while taking the kind of goods being accommodated in the refrigerated volume into account.

[0022] Next, a maximum acceptable relative decay value is derived, based on the high temperature alarm limit and the high temperature alarm delay time. As described above, the high temperature alarm limit and the high temperature alarm delay time in combination define how high a temperature is acceptable inside the refrigerated volume, and for how long. The impact on the stored goods, e.g. in terms of decay, caused by an elevated storage temperature, is determined by the temperature level as well as by the length of the time interval at which the goods are stored at a certain temperature level. Thus, by setting the high temperature alarm limit and the high temperature alarm delay time, it is also defined for how long it can be accepted that the temperature inside the refrigerated volume is at or above the high temperature alarm limit. Accordingly, it is also defined that additional decay of the stored goods, which corresponds to storing the goods at the high temperature alarm limit for a time period corresponding to the high temperature alarm delay time, is acceptable. The derived maximum acceptable relative decay value reflects this.

[0023] Next, the vapour compression system is operated in a normal manner, in order to provide the required cooling to the respective refrigerated volumes. During this, the temperature inside the refrigerated volume is monitored. Furthermore, a weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length, is continuously derived.

[0024] In the present context the term 'weighted mean temperature' should be interpreted to mean a mean value of the measured temperature inside the refrigerated volume, during the moving time window, where the measured temperature values are weighted, e.g. by providing higher temperatures with a higher weight than lower temperatures. Thus, the weighted mean temperature provides a suitable measure for the temperature conditions inside the refrigerated volume, during a time interval corresponding to the moving time window, and without possible rapid fluctuations in the temperature signal, and which provides greater weight to temperature which are significantly above the cut-in temperature than to temperatures slightly above the cut-in temperature, thereby reflecting the severity of the elevated temperature level.

[0025] In the present context the term 'moving time window' should be interpreted to mean a time interval ending at the current point in time, and extending backwards in time for the predefined length. Thus, the beginning of the time interval moves continuously forward in time. Accordingly, the derived weighted mean temperature at all times represents a mean temperature prevailing inside the refrigerated volume during a time interval of the predefined length, immediately preceding the current point in time.

[0026] The predefined length of the moving time window may be a few minutes, or it may be as long as several days or even several weeks.

[0027] In the case that the weighted mean temperature inside the refrigerated volume exceeds the cut-in temperature, a timer is started. Furthermore, monitoring the temperature inside the refrigerated volume and deriving the weighted mean temperature prevailing inside the refrigerated volume, in the manner described above, is continued.

[0028] When the weighted mean temperature inside the refrigerated volume increases to a level above the cut-in temperature, this is an indication that the vapour compression system is unable to keep the temperature inside the refrigerated volume within the specified temperature interval. However, this may also simply be due to a temporary condition which the vapour compression system is able to overcome. Therefore, a warning is not generated immediately.

[0029] Next, a delay time is derived, based on the weighted mean temperature and the maximum acceptable relative decay value. As described above, the maximum acceptable relative decay value represents a decay resulting from storing the goods at the high temperature alarm limit for a time period corresponding to the high temperature alarm delay time, and thereby to a decay which was accepted when the control parameters were set initially. Thus, the delay time is derived based on the weighted mean temperature, which reflects the current temperature level inside the refrigerated volume, and takes the decay, which was accepted when the control parameters were set initially into account.

[0030] The derived delay time could thereby correspond to a storage time, at the current weighted mean temperature, which results in an expected decay which is identical or similar to the maximum acceptable relative decay value. Accordingly, it is considered acceptable that the temperature inside the refrigerated volume is at the weighted mean temperature for a time period corresponding to the derived delay time, in the same manner as it is considered acceptable that the temperature inside the refrigerated volume is at the high temperature alarm limit for a time period corresponding to the high temperature alarm delay time, since this is expected to result in identical or similar relative decay values.

[0031] The derived delay time can therefore be applied as a warning delay time, in the same manner as the hight temperature alarm delay time is applied, and as described above. Accordingly, a warning is generated when the timer reaches the derived delay time.

[0032] Thus, the method according to the invention allows a warning to be generated if the temperature inside the refrigerated volume is above a desired upper temperature limit, but below a high temperature alarm limit, which would normally trigger an alarm. This allows possible faults or non-optimal operation of the vapour compression system, e.g. need for defrosting, refrigerant charge loss, etc., to be detected early. Thereby service or maintenance can be scheduled timely before the vapour compression system is in a critical state which requires immediate attention and possibly results in stored goods having to be discarded.

[0033] According to one embodiment, the timer may be of a kind which has fixed time steps. In this case the derived delay time may specify a number of time steps which the timer needs to count before the delay time has been reached.

[0034] According to another embodiment, the timer may be of a kind which has variable time steps, and the size of the time steps may depend on the weighted mean temperature, in the sense that a high temperature corresponds to smaller time steps than a lower temperature. In this case the delay time may correspond to a fixed number of steps of the timer, and deriving the delay time includes deriving the size of the time steps of the timer.

[0035] The step of deriving a maximum acceptable relative decay value may be performed using a mathematical model.

[0036] According to this embodiment, a suitable mathematical model is applied when the maximum acceptable relative decay value is derived. The mathematical model may advantageously take the kind of goods to be stored in the refrigerated volume into account, in the sense that the mathematical model may reflect how the specific kind of goods would normally decay when stored at various temperatures. Thus, the mathematical model may reflect the temperature sensitivity of the stored goods, the specific heat capacity of the stored goods, etc. For instance, for very temperature sensitive goods, a fast decay may be expected. Furthermore, goods with a high specific heat capacity may be expected to maintain a low temperature inside the goods for some time, even if stored at elevated temperatures, and this will slow the decay.

[0037] The mathematical model may, e.g., be a relative rate of spoilage (RRS) model. Such models are developed on the basis of shelf-life data obtained at different storage temperatures in experiments where shelf-life was determined by sensory evaluation. These models do not take into account the types of reactions which cause spoilage at different temperatures, and this may be considered an advantage in the sense that RRS models can be valid for a wide range of storage temperatures. RRS models are very simple, but still most useful for calculation of shelf-life at different storage temperatures, since it is only necessary to provide the product shelf-life for a single known and constant storage temperature. The RRS model then allows shelf-life to be predicted at different temperatures.

[0038] The mathematical model may, e.g., be an Arrhenius RRS model, e.g. in the form of:

$$Shelf-life\ at\ T°\mathrm{C} = \frac{Shelf-life\ at\ T_{ref}}{Exp\left[\frac{-E_a}{R} \times \left(\frac{1}{T+273} - \frac{1}{T_{ref}+273}\right)\right]}$$

[0039] The method may further comprise the step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value, and the step of deriving a delay time may be based on the weighted mean temperature and the combinations of mean storage temperature and storage time.

[0040] According to this embodiment, once the maximum acceptable relative decay value has been derived, suitable combinations of mean storage temperature and storage time are derived. Each of the combinations of mean storage temperature and storage time results in a relative decay value which corresponds to the maximum acceptable relative decay value. This could, e.g., be done upfront, for instance when the control parameters are initially set and the maximum acceptable relative decay value is derived.

[0041] Subsequently, during operation of the vapour compression system, a delay time can easily be derived, based on the weighted mean temperature, simply by consulting the previously derived combinations of mean storage temperature and storage time, and selecting the combination which includes the weighted mean temperature. This allows for fast and reliable determination of the delay time which is relevant under the given circumstances.

[0042] The step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value may be performed using a mathematical model.

[0043] This is similar to the situation regarding deriving the maximum acceptable relative decay value described above, and the remarks set forth in this regard are therefore equally applicable here. The applied mathematical model may, e.g., be the same in both cases.

[0044] The step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value may comprise generating a look-up table and/or a graph.

[0045] According to this embodiment, the derived combinations are stored in the form of a look-up table and/or a graph, which can be consulted when the delay time needs to be derived during operation of the vapour compression system.

[0046] The step of deriving a delay time may be performed continuously, based on the continuously derived weighted mean temperature, thereby obtaining a dynamically updated delay time.

[0047] According to this embodiment, the temperature inside the refrigerated volume is continuously monitored in order to continuously derive the weighted mean temperature, after the temperature has increased above the cut-in temperature. This continuously derived weighted mean temperature is then used for continuously deriving a delay time, which corresponds to the currently occurring weighted mean temperature. Thereby the derived delay time is continuously adjusted to reflect the actually occurring temperature inside the refrigerated volume. For instance, in the case that the temperature inside the refrigerated volume continues to increase, this is taken into account, and the delay time is decreased, thereby causing the warning to be generated earlier.

[0048] The method may further comprise the step of, in the case that the weighted mean temperature inside the refrigerated volume decreases below the cut-in temperature, stopping and resetting the timer.

[0049] According to this embodiment, if the weighted mean temperature decreases below the cut-in temperature before the delay time is reached, this is an indication that the vapour compression system is in fact capable of maintaining an acceptable temperature level inside the refrigerated volume, even though the weighted mean temperature was temporarily above the cut-in temperature. Accordingly, in this case it is not necessary to generate a warning. Therefore, the timer is stopped and reset, the delay time will accordingly not be reached, and a warning is not generated.

[0050] The weighted mean temperature may be a mean kinetic temperature (MKT). The MKT is defined by the International Conference on Harmonization (ICH) as a single derived temperature, which, if maintained over a defined period, would afford the same thermal challenge to a pharmaceutical product as would have been experienced over a range of both higher and lower temperatures for an equivalent defined period. The MKT yields a higher temperature than a simple arithmetic mean, and may be calculated using the Arrhenius equation mentioned above. The MKT quantifies the cumulative thermal stress to which a product has been subjected when placed at varying temperatures during transport or storage. The MKT provides higher temperatures with greater weights by computing the natural logarithm of the absolute temperature. For instance, the MKT may be calculated using Haynes' formula:

$$T_k = \frac{\Delta H | R}{-ln \frac{e^{\frac{-\Delta H}{RT_1}} + e^{\frac{-\Delta H}{RT_2}} + \cdots + e^{\frac{-\Delta H}{RT_n}}}{n}}$$

where T_k is MKT in kelvin, ΔH is the heat of activation or activation energy, R is the universal gas constant, T_i is the temperature in kelvin during the i'th time period, and n is the total number of equal time periods over which data has been collected.

[0051] The method may further comprise the step of scheduling inspection or maintenance of the vapour compression system in response to a generated warning.

[0052] As described above, when a warning is generated, this is an indication that the vapour compression is, for some reason, not capable of maintaining the temperature inside the refrigerated volume within a desired temperature range. This could, e.g., be due to ice formation on the evaporator, refrigerant loss, malfunctioning components, e.g. fans, valves, sensors, compressors, etc. in any event, this may require inspection, and possibly maintenance or repair, of the vapour compression system. Therefore, this may advantageously be scheduled in response to a generated warning.

[0053] Since the warning is generated before the high temperature alarm limit is reached, and thereby before the state of the vapour compression system is critical, scheduling the inspection or maintenance is not urgent, and it can therefore be scheduled at a convenient time, e.g. during normal working hours of the maintenance personnel, during closing hours of a store accommodating the vapour compression system, during a time slot where relevant maintenance personnel is available, etc.

[0054] The method may further comprise the step of resetting the moving time window upon completion of the scheduled inspection or maintenance.

[0055] According to this embodiment, when maintenance personnel has arrived at the site, the inspection will be performed, and the cause of the elevated temperature will typically be identified and alleviated. Thus, when the maintenance personnel has completed the task, it can be assumed that the vapour compression system is now operating correctly. Therefore, in order to avoid that a new warning is generated, based on temperature measurements performed before the inspection or maintenance was performed, the moving time window may be reset, thereby ensuring that, going forward, the weighted mean temperature is derived based on measurements performed after completion of the inspection or maintenance, thereby reflecting the new conditions prevailing in the vapour compression system.

[0056] In addition, the warning may be reset, thereby indicating that the issue causing the elevated temperature inside the refrigerated volume has been dealt with.

[0057] Alternatively or additionally, the warning may be reset if the weighted mean temperature inside the refrigerated volume decreases below the cut-in temperature, even if inspection or maintenance has not been scheduled. Furthermore, a scheduled inspection may be cancelled if the weighted mean temperature decreases below the cut-in temperature after the inspection has been scheduled, but before it has been performed. In this case it can be assumed that the vapour compression system has been able to overcome the issues which caused the elevated temperature inside the refrigerated volume, and that inspection or maintenance is therefore not required.

[0058] The step of setting control parameters related to the refrigerated volume may further comprise setting a cut-out temperature.

[0059] According to this embodiment, a cut-out temperature is set in addition to the cut-in temperature, the high temperature alarm limit and the high temperature alarm delay time. In the present context the term 'cut-out temperature' should be interpreted to mean a temperature value which triggers closing of the expansion valve which supplies refrigerant to the evaporator being arranged in thermal contact with the refrigerated volume. Thus, when the temperature inside the refrigerated volume has decreased to the cut-out temperature, then the expansion valve is closed, thereby preventing a flow of refrigerant to the evaporator. This will cause the temperature inside the refrigerated volume to increase. Thus, by setting the cut-out temperature it is determined at which temperature level the expansion valve should be closed for that particular refrigerated volume. As an alternative, in the case that the expansion device is controlled in accordance with a reference temperature, the cut-out temperature forms the lower boundary of a temperature interval between the cut-out temperature and the cut-in temperature, with the reference temperature in the middle of the temperature interval.

[0060] The cut-in temperature and the cut-out temperature may be set in dependence of each other. For instance, a specific absolute temperature may be selected for the cut-out temperature, and the cut-in temperature may be specified as a certain temperature interval above the cut-out temperature, e.g. 2°C or 3°C above the cut-out temperature.

[0061] The vapour compression system may comprise at least two expansion devices and at least two evaporators, each expansion device controlling a refrigerant supply to one of the evaporators, and the method may further comprise the step of performing diagnosis of the vapour compression system based on one or more warnings originating from the refrigerated volumes being arranged in thermal contact with the evaporators.

[0062] According to this embodiment, the vapour compression system is of a kind which comprises at least two refrigerated volumes, each being cooled by a separate evaporator. The vapour compression system could, e.g., be of the kind which may be installed in a supermarket, comprising several display cases.

[0063] When a warning is generated in the manner described above, this may be due to issues related to the individual refrigerated volumes, e.g. ice formation on the evaporator, a malfunctioning fan, etc. However, it may also be due to issues which are related to the entire vapour compression system, and which may therefore affect several refrigerated volumes. Such issues may include loss of refrigerant charge, a malfunctioning condenser fan, a malfunctioning compressor, etc. By simultaneously monitoring warnings originating from the various refrigerated volumes, information may be derived regarding the nature of the issues causing the warnings. For instance, if only one refrigerated volume generates a warning, then the cause of the warning is most likely related to that refrigerated volume. On the other hand, if several refrigerated volumes generate warnings, then the cause of the warnings may be related to the entire vapour compression system, e.g. loss of refrigerant charge. Accordingly, analysing the generated warnings in this manner may provide an indication for the maintenance personnel with regard to identifying the cause of the warning(s), thereby leading to a faster conclusion and alleviation of the issue.

[0064] Thus, the step of performing diagnosis of the vapour compression system may comprise determining that a system related fault is occurring in the case that warnings originating from two or more refrigerated volumes occur within a predefined time interval, e.g. if warnings originating from two or more refrigerated volumes are active simultaneously.

BRIEF DESCRIPTION OF THE DRAWINGS

[0065] The invention will now be described in further detail with reference to the accompanying drawings in which

Fig. 1 is a diagrammatic view of a vapour compression system being operated in accordance with a method according to a first embodiment of the invention,

Fig. 2 is a diagrammatic view of a vapour compression system being operated in accordance with a method according to a second embodiment of the invention,

Fig. 3 illustrates temperature inside a refrigerated volume as a function of time, including various temperature limits,

Fig. 4 illustrates deriving a delay time in accordance with a method according to an embodiment of the invention,

Fig. 5 illustrates temperature inside a refrigerated volume as a function of time while ice formation is building up on the evaporator,

Fig. 6 illustrates generated warnings and alarms as a function of time in a vapour compression system comprising multiple refrigerated volumes, and being operated in accordance with a method according to an embodiment of the invention, and

Fig. 7 is a detail of the graph of Fig. 6.

DETAILED DESCRIPTION OF THE DRAWINGS

[0066] Fig. 1 is a diagrammatic view of a vapour compression system 1 being operated in accordance with a method according to a first embodiment of the invention. The vapour compression system 1 comprises a compressor unit 2, a heat rejecting heat exchanger 3, an expansion device 4 and an evaporator 5 arranged in a refrigerant path. A fan 6 is arranged to drive a secondary fluid flow across the heat rejecting heat exchanger 3.

[0067] During operation of the vapour compression system 1, refrigerant flowing in the refrigerant path is compressed by means of the compressor(s) of the compressor unit 2 before being supplied to the heat rejecting heat exchanger 3. When the refrigerant passes through the heat rejecting heat exchanger 3, heat exchange takes place between the refrigerant and the secondary fluid flow driven by the fan 6, in such a manner that heat is rejected from the refrigerant.

[0068] The refrigerant leaving the heat rejecting heat exchanger 3 is supplied to the expansion device 4, where it undergoes expansion before being supplied to the evaporator 5. When passing through the evaporator 5, heat exchange takes place between the refrigerant and air inside a refrigerated volume arranged in thermal contact with the evaporator 5, in such a manner that heat is absorbed by the refrigerant, while the liquid part of the refrigerant is at least partly evaporated. Accordingly, cooling is thereby provided to the refrigerated volume. Finally, the refrigerant is once again supplied to the compressor unit 2.

[0069] The supply of refrigerant to the evaporator 5 is controlled by means of the expansion device 4. The supply of refrigerant is controlled in order to obtain a temperature inside the refrigerated volume which is within a desired temperature interval. Accordingly, when the temperature inside the refrigerated volume reaches a specified cut-in temperature, the expansion device 4 is opened, thereby allowing a supply of refrigerant to the evaporator 5 and causing the temperature inside the refrigerated volume to decrease. When the temperature inside the refrigerated volume reaches a cut-out temperature, the expansion device 4 is closed, thereby preventing a supply of refrigerant to the evaporator 5, and causing the temperature inside the refrigerated volume to increase again, until the cut-in temperature is reached, etc. As described above, the expansion device 4 may alternatively be controlled in accordance with a reference temperature in the middle of a temperature interval between the cut-out temperature and the cut-in temperature.

[0070] Initially, at least the cut-in temperature, the cut-out temperature, a high temperature alarm limit and a high temperature alarm delay time are set. The high temperature alarm limit represents a temperature value, above the desired temperature interval, which triggers generation of a high temperature alarm, and the high temperature alarm delay time defines a delay time which is allowed to elapse from the high temperature alarm limit is reached and until the high temperature alarm is actually generated. Accordingly, the high temperature alarm delay time represents a dwelling time during which it is considered acceptable that a temperature at or above the high temperature alarm limit is occurring inside the refrigerated volume.

[0071] Furthermore, a maximum acceptable relative decay value is derived, based on the high temperature alarm limit and the high temperature alarm delay time. Thus, the maximum acceptable relative decay value represents an expected decay of goods stored in the refrigerated volume, when the temperature inside the refrigerated volume is at a level corresponding to the high temperature alarm for a time period corresponding to the high temperature alarm delay time.

[0072] While the vapour compression system 1 is operated in the manner described above, the temperature inside the refrigerated volume is monitored, and a weighted mean temperature prevailing inside the refrigerated volume is continuously derived, during a moving time window of a predefined length.

[0073] In the case that the weighted mean temperature inside the refrigerated volume exceeds the cut-in temperature, a timer is started. Furthermore, the weighted mean temperature is continuously derived, based on the monitored temperature inside the refrigerated volume, and a delay time is dynamically derived, based on the weighted mean temperature and the previously derived maximum acceptable relative decay value. The delay time represents a storage time at the weighted mean temperature, which results in a relative decay value corresponding to the maximum acceptable relative decay value.

[0074] When the timer reaches the delay time, a warning is generated. Based on the generated warning, inspection or maintenance of the vapour compression system 1 may be scheduled, in order to remove the cause of the elevated temperature.

[0075] Since the warning is generated when the temperature inside the refrigerated volume has been above a desired upper temperature limit for a certain time, but before a high temperature alarm limit has been reached, it is possible to detect issues which affect the operation of the vapour compression system 1 to the effect that it is difficult to maintain the temperature inside the refrigerated volume within a desired temperature interval, at an early stage. Thereby such issues can be addressed before the operation of the vapour compression system 1 becomes critical.

[0076] Fig. 2 is a diagrammatic view of a vapour compression system 1 being operated in accordance with a method according to a second embodiment of the invention. The vapour compression system 1 of Fig. 2 is very similar to the vapour compression system 1 of Fig. 1, and it will therefore not be described in detail here.

[0077] The vapour compression system 1 comprises a number of expansion devices 4, two of which are shown, each being arranged to supply refrigerant to a separate evaporator 5. Each of the evaporators 5 is arranged in thermal contact with a separate refrigerated volume. Thus, each of the expansion devices 4 is controlled in order to allow or prevent a flow of refrigerant to the respective evaporators 5, in order to maintain the temperature inside the respective refrigerated volumes within respective specified temperature intervals, essentially in the manner described above with reference to Fig. 1. Furthermore, warnings may be generated with respect to each of the refrigerated volumes, independently of the other refrigerated volumes, essentially in the manner described above with reference to Fig. 1.

[0078] In the vapour compression system 1 of Fig. 2, the entire vapour compression system 1 is further monitored by simultaneously monitoring the warnings generated in relation to all of the refrigerated volumes. In the case that several refrigerated volumes generate warnings substantially simultaneously, or within a limited time interval, this may be an indication that the issue causing the warnings may be system related, e.g. loss of refrigerant charge or malfunctioning of the condenser fan 6. On the other hand, if only one of the refrigerated volumes generates a warning, then it is more likely that the issue causing the warning is related to that specific refrigerate volume, e.g. defrost requiring ice formation on the corresponding evaporator 5.

[0079] Fig. 3 is a graph illustrating weighted mean temperature inside a refrigerated volume as a function of time. A cut-out temperature of 2°C, a cut-in temperature of 4°C and a high temperature alarm limit of 8°C are marked. Furthermore, a maximum desirable temperature value of 5°C is marked. The temperature curve 7 represents temperature variations inside the refrigerated volume when the vapour compression system is operated in accordance with a prior art method.

[0080] Initially, the temperature 7 is kept within a temperature interval between the cut-out temperature and the cut-in temperature, i.e. the vapour compression system is performing as expected. However, at t=ti, the temperature 7 exceeds the cut-in temperature, and continues to increase above the 5°C limit at $t=t_2$. The temperature 7 remains above the 5°C temperature limit for a long period of time, while slowly increasing, and reaches the high temperature alarm limit at $t=t_3$. Then a timer is started, and an alarm is generated when the specified high temperature alarm delay time has elapsed, at $t=t_4$.

[0081] It can be seen that the slow increase in temperature after $t=t_1$ has the consequence that the temperature inside the refrigerated volume is above the 5°C limit for a very long period of time before the alarm is generated, and the operator is thereby made aware of the elevated temperature. This may have an undesirable impact on the shelf-life or quality of the goods being stored in the refrigerated volume.

[0082] If, on the other hand, the vapour compression system had been operated in accordance with a method according to an embodiment of the invention, the following would have happened.

[0083] When the temperature 7 exceeds above the cut-in temperature at $t=t_1$, a timer is started, and a delay time is dynamically derived, based on the weighted mean temperature and a maximum acceptable relative decay, which corresponds to storing goods at 8°C for a period of time corresponding to the high temperature alarm delay time. When the delay time is reached, indicated at $t=t_5$, a warning is generated. Thus, the operator is warned of the increased temperature level at a significantly earlier point in time, and before the elevated temperature becomes critical. This allows inspection or maintenance of the vapour compression system to be timely scheduled, and may improve the quality and/or shelf-life of goods being stored in the refrigerated volume.

[0084] Fig. 4 illustrates deriving a delay time in accordance with a method according to an embodiment of the invention. Similarly to the situation illustrated in Fig. 3, a cut-in temperature of 4°C and a high temperature alarm limit of 8°C are selected. Furthermore, the hight temperature alarm delay time is set to 30 minutes.

[0085] A maximum acceptable relative decay value is derived, based on the high temperature alarm limit and the high temperature alarm delay time. Thus, the maximum acceptable relative decay value corresponds to an expected decay of stored goods when stored at the high temperature alarm limit, i.e. at 8°C, for a period of time corresponding to the high temperature alarm delay time, i.e. for 30 minutes. This may, e.g., include applying a suitable mathematical model.

[0086] The derived maximum acceptable relative decay value is then used for deriving delay times as a function of storage temperature, in such a manner that a relative decay value corresponding to the maximum acceptable relative decay value is obtained for each pair or combination of storage temperature and delay time. This may also include applying an appropriate mathematical model. The curve 8 of Fig. 4 represents these values. It can be seen that a storage temperature corresponding to the cut-in temperature, i.e. 4°C results in a delay time of 50 minutes. As the storage temperature increases, the delay time decreases, indicating that a high storage temperature is acceptable for a shorter time period than a lower storage temperature.

[0087] When a delay time is to be derived during operation of the vapour compression system, the graph of Fig. 4 is simply consulted, and a delay time can be readily determined, based on the weighted mean temperature.

[0088] Fig. 5 illustrates temperature inside a refrigerated volume as a function of time while ice formation is building up on the evaporator. Curve 9 represents measured temperature, and curve 10 represents weighted mean temperature, in the form of MKT, during a moving time window. Line 11 represents high temperature alarm state, and line 12 represents a warning state in accordance with the present invention. The cut-out temperature is set to 0°C, the cut-in temperature is set to 2°C, and the high temperature alarm limit is set to 8°C.

[0089] It can be seen that the vapour compression system is initially performing as expected, and the temperature is kept between the cut-out temperature and the cut-in temperature. However, on 11 September around noon, ice starts to build up on the evaporator, causing the temperature 9 inside the refrigerated volume to gradually increase, and exceeding the cut-in temperature at approximately 6 pm. A bit later the MKT 10 also starts to increase, and the MKT 10 exceeds the cut-in temperature around midnight. This starts a timer, and a delay time is dynamically derived, in the manner described above, and a warning is generated, setting the warning state 12 to '1', when the delay time is reached.

[0090] However, inspection is not scheduled fast, and the temperature 9 as well as the MKT 10 continues to increase until the temperature 9 exceeds the high temperature alarm limit shortly after noon on 12 September. This causes an alarm to be generated when the high temperature alarm delay time has lapsed shortly thereafter, setting the alarm state 11 to '1'.

[0091] On 13 September shortly before noon, maintenance staff arrives at the site and performs a defrost procedure which removes the cause of the elevated temperature. Afterwards, the alarm state 11 and the warning state 12 are reset to '0'. Furthermore, the moving time window is reset, thereby ensuring that the MKT 10 is subsequently derived based on temperature measurements 9 performed after the defrost procedure was completed.

[0092] Fig. 6 illustrates generated warnings and alarms as a function of time in a vapour compression system comprising multiple refrigerated volumes, and being operated in accordance with a method according to an embodiment of the invention. The vapour compression system could, e.g., be the vapour compression system illustrated in Fig. 2. More specifically, curve 13 represents number of warnings generated in accordance with a method according to the invention, and curve 14 represents number of generated high temperature alarms. It can be seen that the number of generated warnings 13 is generally higher than the number of generated high temperature alarms 14. Furthermore, in some periods of time, the number of generated warnings 13 is relatively high. This indicates that the issue or issues causing the warnings may be system related, in the sense that it may be something which affects several refrigerated volumes, e.g. loss of refrigerant charge. This can be detected by viewing the warnings 13 generated from all of the refrigerated volumes in combination, rather than handling them separately. Furthermore, this could not have been detected on the basis of the generated high temperature alarms 14.

[0093] Fig. 7 is a detail of the graph of Fig. 6. It can be seen that before the first high temperature alarm is generated on 18 July, 4-5 refrigerated volumes have already generated warnings, thereby allowing relevant actions to be taken in a timely manner.

Claims

1. A method for operating a vapour compression system (1), the vapour compression system (1) comprising a compressor unit (2), a heat rejecting heat exchanger (3), at least one expansion device (4) and at least one evaporator (5) arranged in a refrigerant path, each evaporator (5) being arranged in thermal contact with a refrigerated volume for storing goods, the method comprising the steps of, for at least one of the refrigerated volumes:

   - setting control parameters related to the refrigerated volume, including setting a cut-in temperature, a high temperature alarm limit and a high temperature alarm delay time,
   - deriving a maximum acceptable relative decay value, based on the high temperature alarm limit and the high temperature alarm delay time,
   - operating the vapour compression system (1) while monitoring a temperature inside the refrigerated volume and continuously deriving a weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length,
   - in the case that the weighted mean temperature inside the refrigerated volume exceeds the cut-in temperature, starting a timer and continuing to derive the weighted mean temperature prevailing inside the refrigerated volume, during a moving time window of a predefined length,
   - deriving a delay time, based on the weighted mean temperature and the maximum acceptable relative decay value, and
   - generating a warning when the timer reaches the derived delay time.

2. A method according to claim 1, wherein the step of deriving a maximum acceptable relative decay value is performed using a mathematical model.

3. A method according to claim 1 or 2, further comprising the step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value, and wherein the step of deriving a delay time is based on the weighted mean temperature and the combinations of mean storage temperature and storage time.

4. A method according to claim 3, wherein the step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value is performed using a mathematical model.

5. A method according to claim 3 or 4, wherein the step of deriving combinations of mean storage temperature and storage time resulting in a relative decay value corresponding to the derived maximum acceptable relative decay value comprises generating a look-up table and/or a graph.

6. A method according to any of the preceding claims, wherein the step of deriving a delay time is performed continuously, based on the continuously derived weighted mean temperature, thereby obtaining a dynamically updated delay time.

7. A method according to any of the preceding claims, further comprising the step of, in the case that the weighted mean temperature inside the refrigerated volume decreases below the cut-in temperature, stopping and resetting the timer.

8. A method according to any of the preceding claims, wherein the weighted mean temperature is a mean kinetic temperature (MKT).

9. A method according to any of the preceding claims, further comprising the step of scheduling inspection or maintenance of the vapour compression system (1) in response to a generated warning.

10. A method according to claim 9, further comprising the step of resetting the moving time window upon completion of the scheduled inspection or maintenance.

11. A method according to any of the preceding claims, wherein the step of setting control parameters related to the refrigerated volume further comprises setting a cut-out temperature.

12. A method according to any of the preceding claims, wherein the vapour compression system (1) comprises at least

two expansion devices (4) and at least two evaporators (5), each expansion device (4) controlling a refrigerant supply to one of the evaporators (5), wherein the method further comprises the step of performing diagnosis of the vapour compression system (1) based on one or more warnings originating from the refrigerated volumes being arranged in thermal contact with the evaporators (5).

13. A method according to claim 12, wherein the step of performing diagnosis of the vapour compression system (1) comprises determining that a system related fault is occurring in the case that warnings originating from two or more refrigerated volumes occur within a predefined time interval.

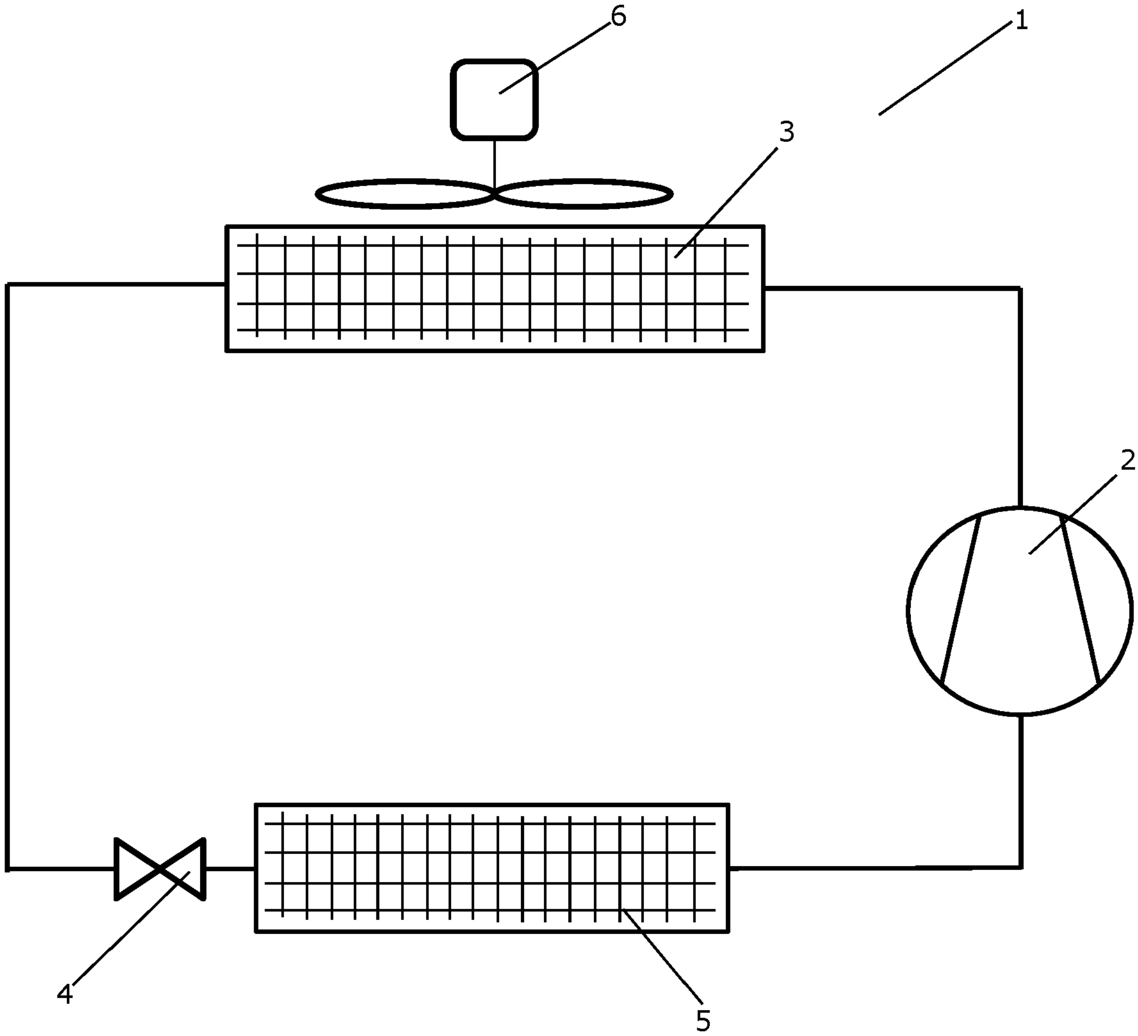


Fig. 1

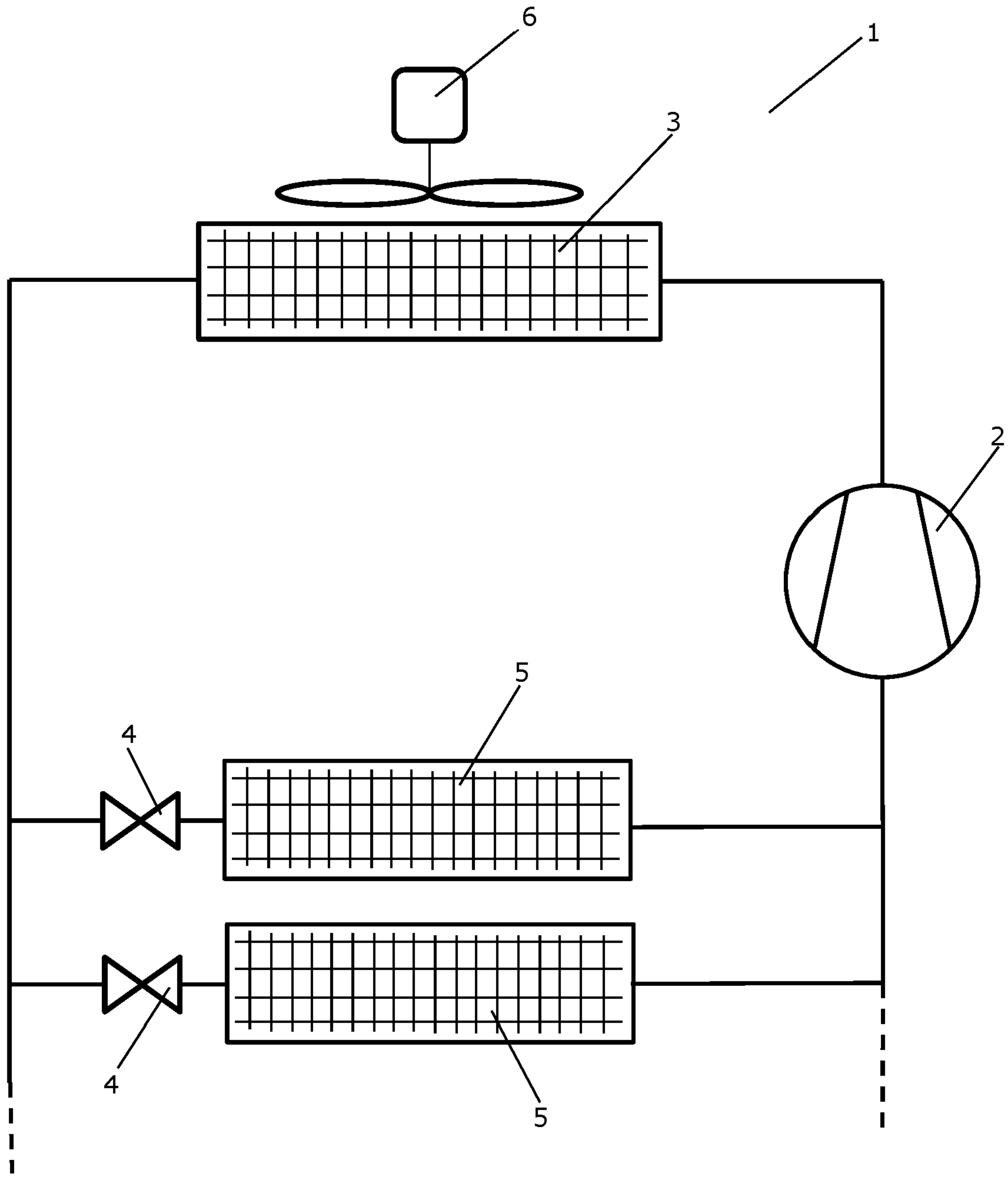


Fig. 2

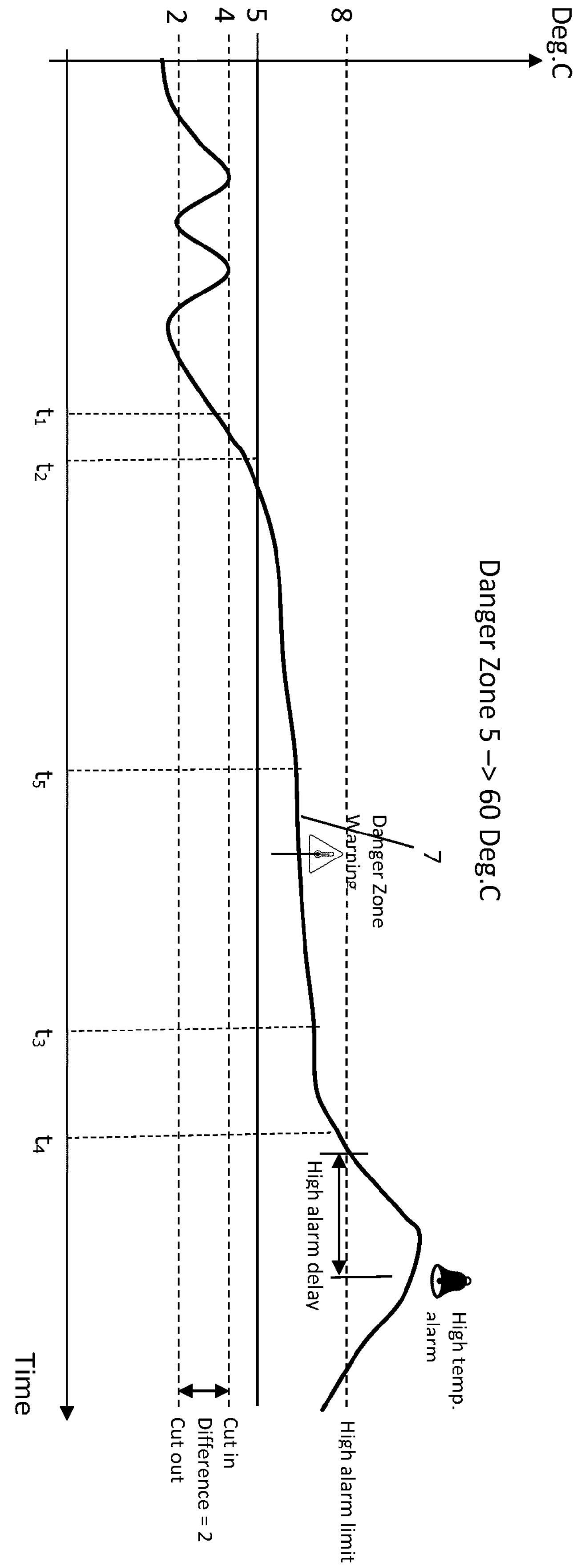

Deg.C
8
5
4
2
Danger Zone 5 –> 60 Deg.C
7
Danger Zone Warning
t_1
t_2
t_5
t_3
t_4
High alarm delay
High temp. alarm
Time
High alarm limit
Cut in
Difference = 2
Cut out

Fig. 3

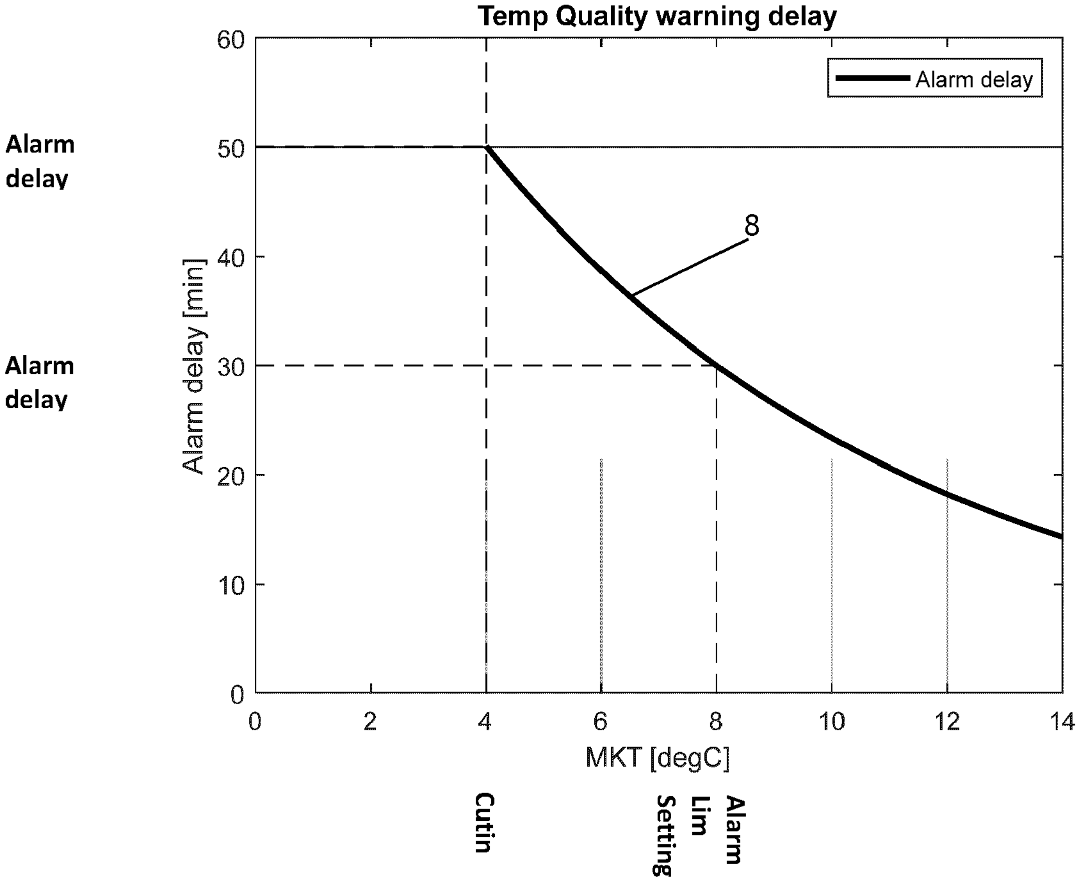
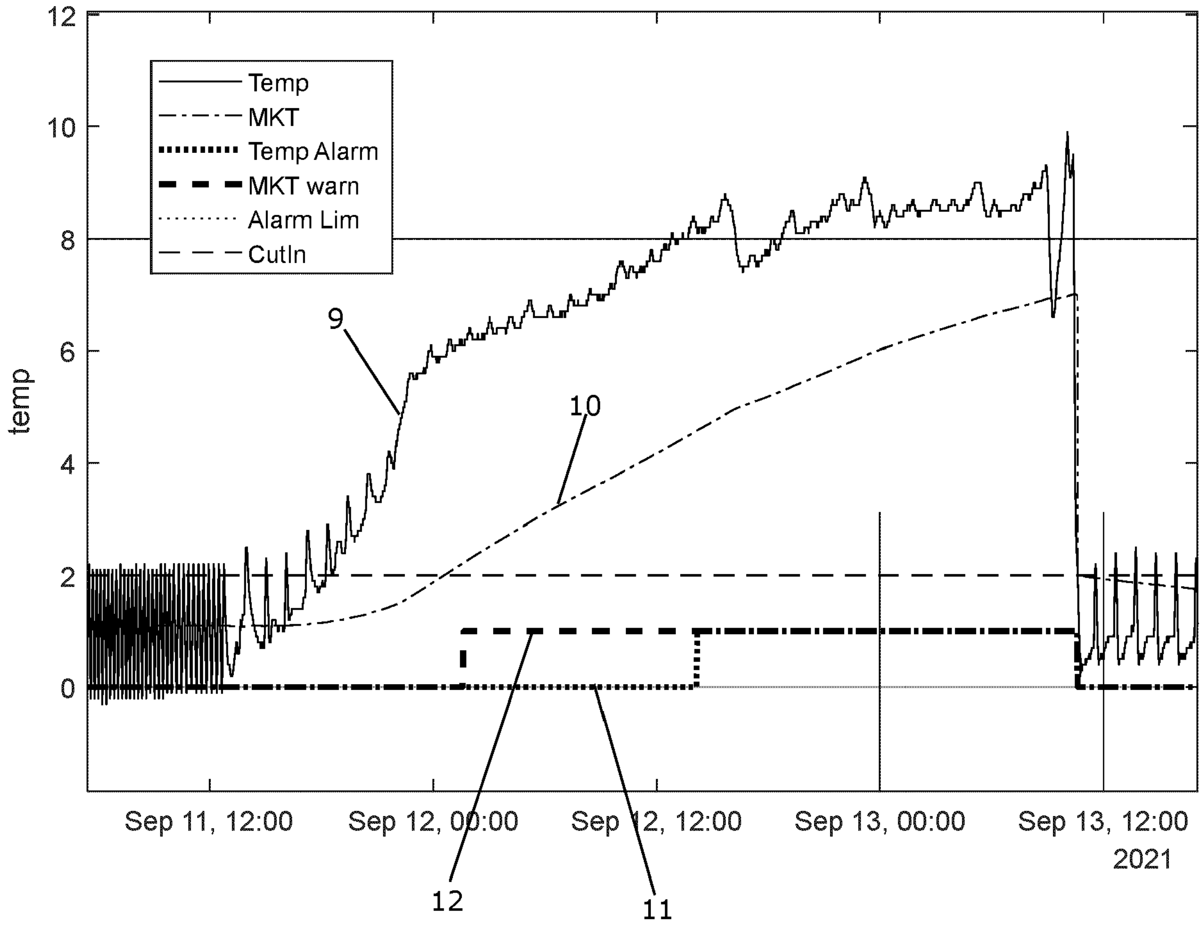

Temp Quality warning delay
Alarm delay
Alarm delay
Alarm delay
8
Alarm delay [min]
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
MKT [degC]
Cutin
Setting
Lim
Alarm

Fig. 4



Temp
MKT
Temp Alarm
MKT warn
Alarm Lim
CutIn
12
10
8
6
4
2
0
temp
9
10
12
11
Sep 11, 12:00
Sep 12, 00:00
Sep 12, 12:00
Sep 13, 00:00
Sep 13, 12:00
2021

Fig. 5

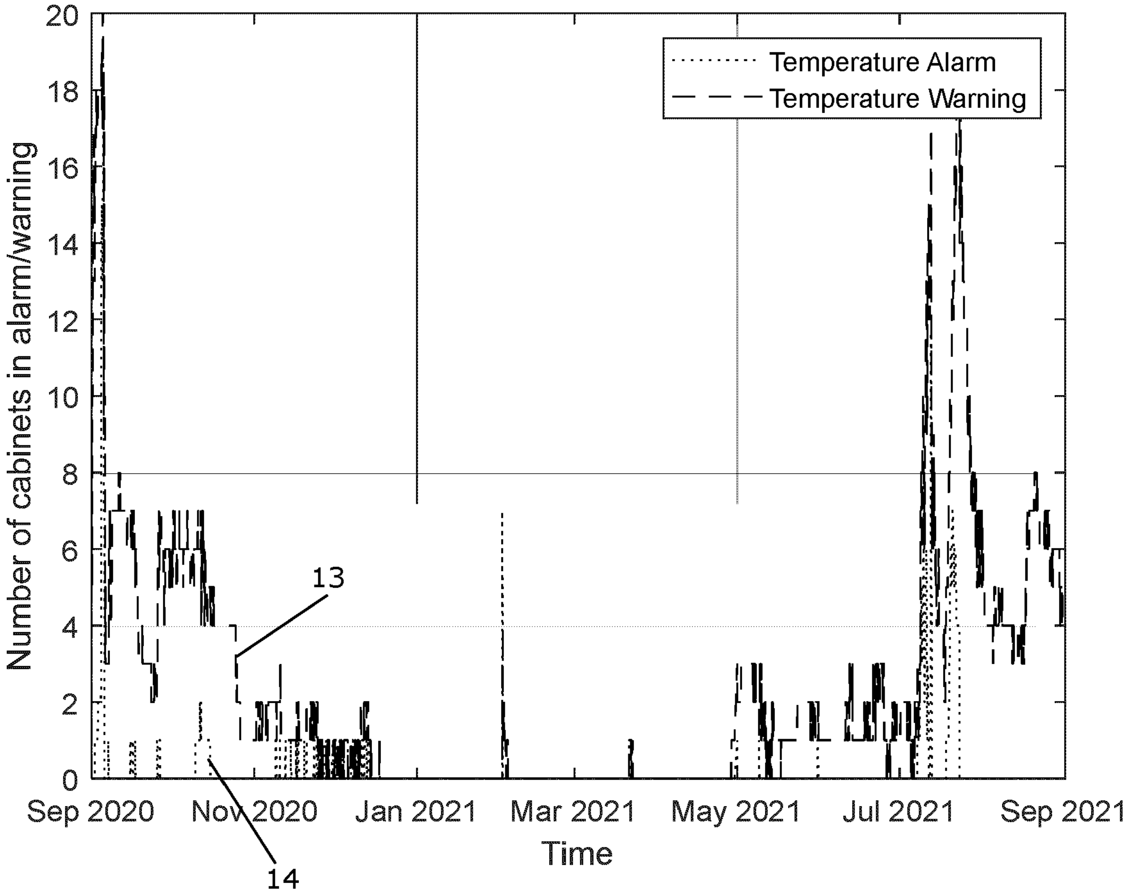

20
18
16
14
12
10
8
6
4
2
0
Number of cabinets in alarm/warning
Temperature Alarm
Temperature Warning
13
14
Sep 2020
Nov 2020
Jan 2021
Mar 2021
May 2021
Jul 2021
Sep 2021
Time

Fig. 6

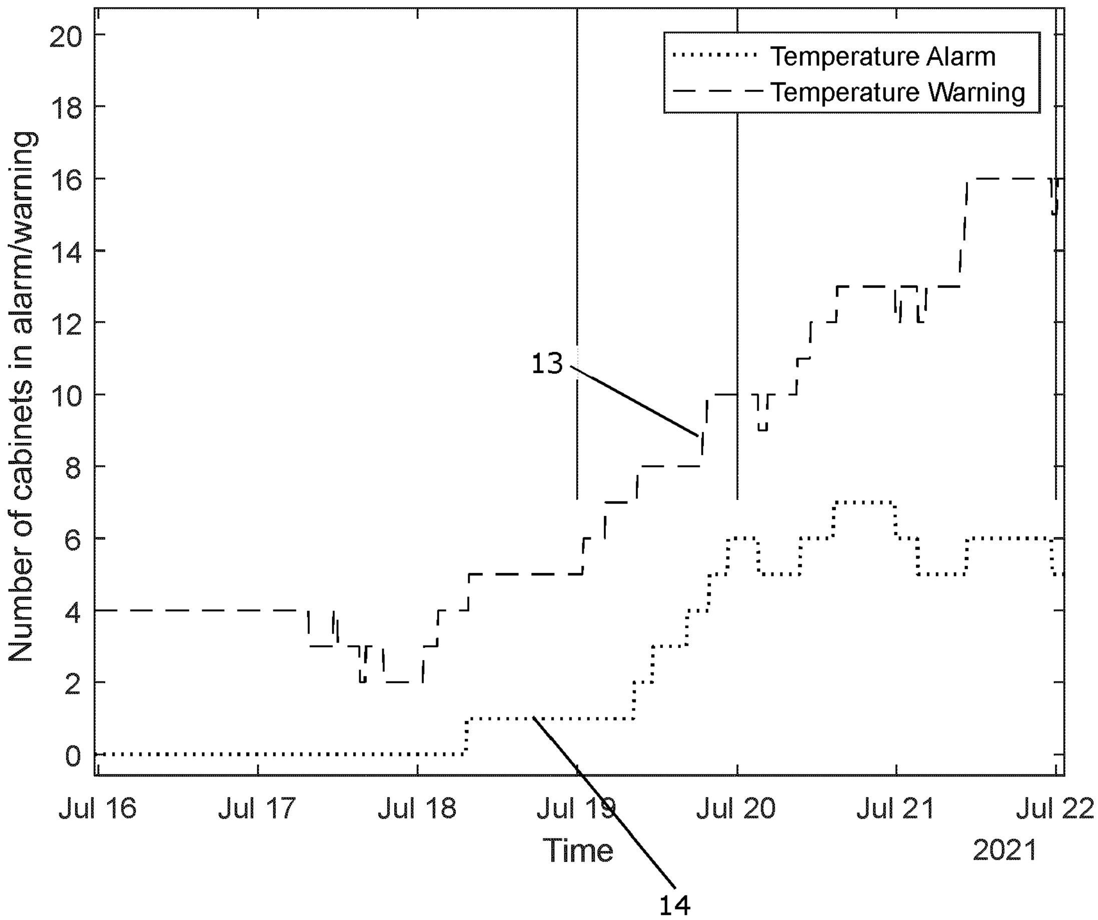

Temperature Alarm
Temperature Warning
Number of cabinets in alarm/warning
0
2
4
6
8
10
12
14
16
18
20
Jul 16
Jul 17
Jul 18
Jul 19
Jul 20
Jul 21
Jul 22
2021
Time
13
14

Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 22 15 6342

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2009/093917 A1 (SMITH SETH [US]) 9 April 2009 (2009-04-09) * paragraph [0088] - paragraph [0098]; figures 4-6 *	1-13	INV. F25B5/02 F25B49/00 F25D29/00 F25B49/02
A	US 2007/157640 A1 (BOLGER MARY K [US] ET AL) 12 July 2007 (2007-07-12) * the whole document *	1-13	
A	EP 3 015 803 A1 (DANFOSS AS [DK]) 4 May 2016 (2016-05-04) * the whole document *	1-13	

TECHNICAL FIELDS SEARCHED (IPC)

F25B
F25D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	22 July 2022	Lucic, Anita

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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22-07-2022

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