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(54) **Temperature control systems**

(57) We describe systems and methods for controlling the internal temperature of cooling apparatus without using a temperature sensor inside the cooled zone. In one embodiment a refrigerator comprises: a thermally insulated cooled zone with a door to enable user access; a cooling system to cool the cooled zone; a control unit coupled to control the cooling system; and a temperature sensor coupled to the control unit. The temperature sensor is outside the cooled zone to sense an ambient tem-

perature of the refrigerator and stores apparatus characterising data characterising a relationship between a pattern of operation of the cooling system and a temperature of the cooled zone for a plurality of different ambient temperatures. The control unit controls the pattern of operation of the cooling system responsive to the sensed ambient temperature and stored apparatus characterising data to adjust the temperature of the cooled zone towards a target temperature.

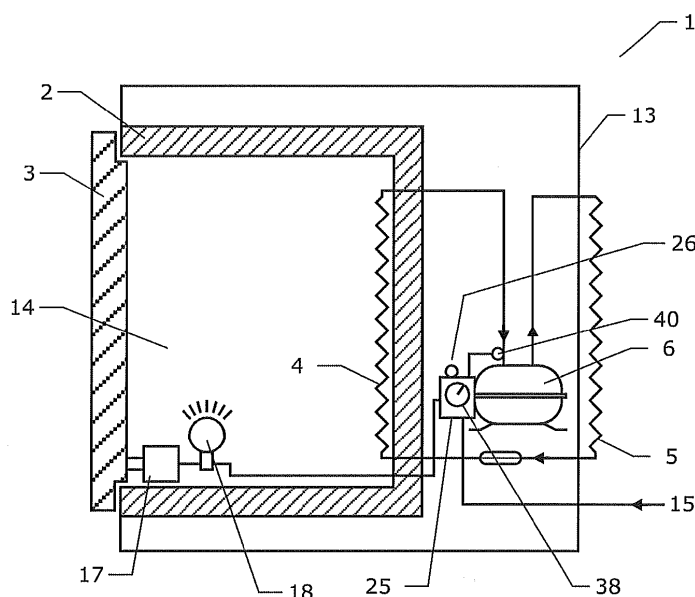


Fig 6

Description

FIELD OF THE INVENTION

[0001] This invention relates to cooling apparatus such as food or drinks coolers, refrigerators and freezers for domestic or commercial use where the cooling effect is adjusted by operating the cooling mechanism (such as a gas/compressor, absorption or peltier cooler), in particular in an on-off-on-off cycle.

BACKGROUND OF THE INVENTION

[0002] Very commonly, control of the cooling effect is managed by adjusting the on- and/or off-periods in the operating cycle, usually under control of a thermostatic switch that is activated by a sensing device inserted into the cooled zone in the apparatus. The on/off cycling is determined by the temperature hysteresis of the thermostat (difference between the higher temperature at which the switch closes to start the cooling mechanism and the lower temperature at which it opens to stop the cooling mechanism), heat capacities, thermal resistances and thermal lags associated with the apparatus. Larger temperature hysteresis results in longer on- and off-periods and slower cycling. Though it is an effective method, it suffers a number of drawbacks:

- The thermostatic switch is expensive because it requires fine control of temperature switching points and has to be installed wholly or partly into the cooled zone.
- In the case of coolers and refrigerators, ice may form on the cooling face in the cooling zone (e.g. on the evaporator of a gas-based cooling mechanism). There is a risk that the off-period is not sufficient to allow ice to melt during the off-period so, over a long time, there is a build up of ice which degrades performance and is inconvenient.

SUMMARY OF THE INVENTION

[0003] According to a first aspect of the invention there is therefore provided a refrigerator comprising: a thermally insulated cooled zone having a door to enable a user to access said cooled zone; a cooling system to cool said cooled zone; a control unit coupled to control said cooling system; and a temperature sensor coupled to said control unit, wherein said temperature sensor is outside said cooled zone to sense an ambient temperature of said refrigerator; wherein said control unit stores apparatus characterising data characterising a relationship between a pattern of operation of said cooling system and a temperature of said cooled zone for a plurality of different said ambient temperatures, and wherein said control unit is configured to control a said pattern of operation of said cooling system responsive to said sensed temperature and said stored apparatus characterising

data to adjust said temperature of said cooled zone towards a target said temperature of said cooled zone.

[0004] In this context 'refrigerator' is used broadly to encompass, as well as domestic refrigerators and freezers, other cooling apparatus such as food/drinks coolers. Embodiments of the refrigerator may be considered as providing a 'virtual thermostat', in particular without the need for a temperature sensor located within the cooled zone.

[0005] In some preferred embodiments the refrigerator also includes a mains voltage sensor and the relationship between the mains voltage, cooling system operation, ambient temperature, and target temperature is also characterised and used to compensate for variations in mains voltage supply to a motor of the cooling system.

[0006] Optionally, embodiments of the refrigerator may include a user control coupled to the control unit to adjust the target temperature.

[0007] Preferably the refrigerator includes a door sensor and the control unit is configured to provide additional cooling in response to detection of operation of the door, preferably dependent on the duration for which the door is open. In some preferred embodiments this is achieved by modifying a value of a cooling effect parameter to (temporarily) increase the cooling effect. This is described further later. In embodiments the additional cooling may be dependent upon both the duration for which the door is open and the sensed ambient temperature.

[0008] Optionally, embodiments of the refrigerator may also include a sensor to sense (from outside the cooled zone) an input of heat energy into the cooled zone, for example when a warm item is placed in this zone. The pattern of operation of the cooling system may then again be altered in order to temporarily provide increased cooling.

[0009] In one approach this can be achieved by sensing the temperature of a gas in a portion of a gas circuited cooling system in a return path from the cool zone towards a compressor of the cooling system, more particularly the control unit may be configured to determine one or both of a time average of this temperature and a peak-to-peak variation in this temperature to identify the heat input from an increased average temperature and/or a reduced peak-to-peak temperature variation. Optionally an estimate of the quantity of heat energy input may be made so that the degree of additional cooling may be increased when more heat energy is input to the cooled zone.

[0010] Additionally or alternatively a parameter of an electrical condition of a motor of the cooling system may be sensed to sense the heat input by indirectly sensing the load on the (compressor) motor of the cooling system. This may be achieved by sensing the load current or power and/or the voltage induced on a winding of the motor, preferably an auxiliary winding of the motor.

[0011] Optionally the control unit may detect this input of heat energy conditional on detection of opening the door of the cool zone (a prerequisite for putting a warm

item inside) and/or absence of detection of greater than a threshold change in the sensed ambient temperature and/or absence of detection of greater than a threshold level of change in an electrical condition of the cooling system. Optionally one or more of these additional parameters may be weighted. Using additional data in this way helps to provide more accurate identification of input of heat energy into the cooled zone.

[0012] In some preferred embodiments the control unit is configured to determine the value of a cooling effect parameter from the sensed ambient temperature and other sensed parameters (where implemented) so that the various different sensed parameters may be combined into a single parameter which represents a desired degree of cooling effect to be achieved by the cooling system for the cooled zone. This facilitates implementation of the more complex embodiments. The cooling effect parameter may then be used to determine the pattern of operation of the cooling system, more particularly, and preferably, to determine durations of on and off periods of the cooling system in a generally cyclical pattern of operation. In embodiments for efficient operation the mapping between the cooling effect parameter value and the on/off period durations is such that as the cooling effect parameter reduces (a smaller desired cooling effect) the on-period duration of the cooling system reduces but a cycle time of the pattern of operation remains substantially constant until a minimum on duration is reached. At this point, rather than reduce the on-time further, the cycle time is then increased to reduce the overall proportion of time for which the cooling system (compressor) is on. Conveniently where a single cooling effect parameter is employed a user control may also be provided to enable a user to adjust this parameter, in particular to impose an overall or baseline modification on a value of this parameter to, in effect, set the desired target temperature of the cooled zone.

[0013] In embodiments the control unit may include an ice-control mode, implemented responsive to detection of operation of the cooling system at more than a threshold proportion of on-time for greater than a threshold period. The ice control mode may be configured to reduce or stop the cooling for a period of time, in particular to allow the temperature of the evaporator to rise above a limit set by the melting point of ice (0°C).

[0014] Whilst one preferred implementation of the system relies on the sensing and ambient temperature of the refrigerator, in some applications this may be sufficiently constant not to be necessary.

[0015] Thus in a related aspect of the invention there is provided a refrigerator comprising: a thermally insulated cooled zone having a door to enable a user to access said cooled zone; a cooling system to cool said cooled zone; a control unit coupled to control said cooling system; and a sensor, coupled to said control unit, to sense a voltage of a mains power supply to said cooling system; wherein said control unit stores apparatus characterising data characterising a relationship between a pattern of

operation of said cooling system and a temperature of said cooled zone for a plurality of different said voltages of said mains power supply; and wherein said control unit is configured to control a said pattern of operation of said cooling system responsive to said sensed voltage and said stored apparatus characterising data to adjust said temperature of said cooled zone towards a target said temperature of said cooled zone.

[0016] In the above described aspects and embodiments of the invention the control unit may be implemented in electronic hardware, software, or a combination of the two. Although it is convenient in embodiments to store the apparatus characterising data in non-volatile memory coupled to a processor configured to implement the above described techniques, potentially the apparatus characterising data may effectively be hard wired into a circuit, for example by choosing resistor values or the like. The skilled person will be aware that many variations in the implementation of the above described systems are possible comprising different means for configuring the control unit to implement the above described techniques.

[0017] According to a further related aspect the invention provides a method of controlling the internal temperature of cooling apparatus comprising a thermally insulated cooled zone without using a temperature sensor inside said cooled zone, the method comprising: characterising a relationship between a temperature of said cooled zone, a pattern of operation of a cooling system for said cooled zone, and one or both of an ambient temperature of said cooling apparatus and a voltage of a mains power supply to said cooling system; measuring one or both of said ambient temperature and said mains power supply voltage; and using said relationship to control said pattern of operation in response to said measured ambient temperature/mains power supply voltage to adjust an internal temperature of said cooled zone towards a target temperature without measuring said internal temperature of said cooled zone.

[0018] The invention still further provides cooling apparatus comprising: a thermally insulated cooled zone without a temperature sensor inside said cooled zone; data characterising a relationship between a temperature of said cooled zone, a pattern of operation of a cooling system for said cooled zone, and one or both of an ambient temperature of said cooling apparatus and a voltage of a mains power supply to said cooling system; means for measuring one or both of said ambient temperature and said mains power supply voltage; and means for using said relationship to control said pattern of operation in response to said measured ambient temperature/mains power supply voltage to adjust an internal temperature of said cooled zone towards a target temperature without measuring said internal temperature of said cooled zone.

[0019] In an application where the mains voltage and ambient temperature are both relatively constant, for example, a hotel room drinks cooler (mini-bar), sufficiently

consistent operation may be achievable using simple on: off timer control of the cooling system (compressor) with an optional user control to adjust the on:off duty cycle, for example by adjusting the on period.

[0020] Thus in a further aspect the invention provides a refrigerator comprising: a thermally insulated cooled zone having a door to enable a user to access said cooled zone, and without a temperature sensor inside said cooled zone; a cooling system to cool said cooled zone; a control unit coupled to control said cooling system; and a user control coupled to said control unit; wherein said control unit is configured to control a cyclical pattern of on-off operation of said cooling system, and is responsive to said user control to adjust a duty cycle of said on-off operation.

[0021] Preferably the control unit is responsive to the user control to adjust a duration of an on-period of the cooling system operation duty cycle. The refrigerator may be incorporated into a hotel room mini bar.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

Figure 1 shows cooling apparatus with a thermostatic switch inside the cooled zone;

Figure 2 shows an alternative arrangement with a thermostatic switch inside the cooled zone;

Figure 3 illustrates variation of the temperature of the cooled zone of the apparatus of Figures 1, 2 with on/off operation for cooling systems;

Figure 4 shows a variant of the graph of Figure 3 with a cooling cycle in which the cooling system operates for a greater proportion of the time;

Figure 5 shows variation of a pattern of operation of a cooling system with value of a cooling effect parameter in a refrigerator according to an embodiment of the invention;

Figure 6 shows cooling apparatus according to an embodiment of the invention;

Figure 7 shows an example of a control unit for the cooling apparatus of Figure 6; and

Figure 8 illustrates changes in temperature variation of gas in a cooling system near the exit of an evaporator, illustrating the effect of placing a warm item in the cooling zone.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0023] We will describe a temperature control system

using on/off cyclic control of a cooling mechanism (e.g. compressor/gas, peltier or absorption cooling device); its features and benefits optionally include:

- 5 • Adaption of the timing of the on/off cycle to suit a particular cooling apparatus (e.g. cooler, refrigerator or freezer)
- Adaption of the timing of the on/off cycle according to user control
- 10 • Adaption of the timing of the on/off cycle according to an environmental temperature
- Adaption of the timing of the on/off cycle according to electrical conditions of the motor when running
- Adaption of the timing of the on/off cycle according to a temperature of gas/liquid flow in the cooling circuit
- 15 • Adaption of the timing of the on/off cycle according to mains supply voltage
- Adaption of the timing of the on/off cycle according to opening of an access into a cooled zone
- 20 • Limit of minimum and/or maximum on-period
- Limit of minimum and/or maximum off-period

[0024] We will describe techniques which aim to provide adequate control of temperature of a cooled zone but without a sensor inside the cooled zone, to give benefits of:

- 30 • Reduced cost of parts or assemblies required for the control function
- Reduced cost of assembly of the control device(s) to the cooling apparatus
- Improved reliability of the system by avoiding the need for a sensing device in the cooled zone
- 35 • Reduction of failures in the field

[0025] Referring to Figure 1, cooling apparatus 1 (such as food/drinks coolers, refrigerators and freezers) usually comprise an outer housing 13 enclosing a cooled zone 14 enclosed by insulating wall 2 and door 3. The figure illustrates a gas/compressor cooling mechanism by way of example but other cooling mechanisms are known and in common use. In this example, cooling effect is provided by a gas/liquid circuit comprising motorcompressor 6, condenser 5, expansion restriction 7 and evaporator 4. Heat is taken from the cooled zone by evaporator 4 and heat is rejected to the environment (e.g. air around the apparatus) from condenser 5. Thermoelectric control 8 on the side of the motorcompressor 6 manages the starting and overload protection for the compressor. It includes connections for incoming mains electricity supply 15, connections to electromechanical thermostatic switch 16 and optional door switch 17 and interior light 18. Opening the door causes switch 17 to close, connecting the light to an electrical supply and closing the door opens the switch to turn it off. Thermostatic switch 16 typically comprises sensor bulb 9 connecting to switch 10 via capillary 12. Switch 10 usually is provided with

user control 11 which can be adjusted to change threshold temperatures of the switch so the nominal temperature of the cooled zone can be set as desired. Power to the motorcompressor is controlled by the thermostatic switch. The switch closes to start the motorcompressor when the temperature sensed by the bulb 9 rises above a higher threshold temperature and then opens to stop the motorcompressor when the temperature sensed by the bulb falls below a lower threshold temperature. The thermostatic switch, including sensor bulb etc. have to be constructed to be resistant to the environment of the cooled zone. In particular they must be resistant to moisture and, because the switch is accessible in the cooled zone, the electrical parts have to be robustly insulated to avoid risk of electrical shock to any user.

[0026] Figure 2 shows an alternative thermostat arrangement, using an electronic sensor (20) located in the cooled zone. It connects to an electronic circuit 21 which responds to the sensor and connects or disconnects power to the motorcompressor 6 according to the rise and fall of the temperature sensed by sensor 20 in a similar way to that of the electromechanical thermostatic switch 16 described previously. The electronic circuit may be provided with a user control 22 to adjust the switching threshold temperatures to control the nominal temperature of the cooled zone. Typically the electronic circuit 21 is located outside the cooled zone (but inside the outer housing 2) because the environmental characteristics of the cooled zone reduce the reliability of the circuit and power dissipation in the circuit causes unwanted heating in the cooled zone. Sensor 20, which is usually a thermistor but could be some other temperature sensitive device (e.g. thermocouple, temperature-sensitive resistor or semiconductor junction), is located in the cooled zone to provide accurate sensing of temperature with short time lag. It has to be constructed so it is resistant to the environment of the cooled zone, particularly from ingress of water or humidity. The electronic circuit 21 and sensor 20 often operate at hazardous voltages so it is necessary to provide strong insulation to avoid risk of electrical shock to users. This is particularly important for sensor 20 because it is exposed in the accessible cooled zone and may be covered in condensation or ice which can act as an electrical path through very small gaps in any enclosure of the sensor. The advantages of using an electronic temperature control system are that finer and/or more accurate temperature control is possible and other user benefits can be provided (e.g. display of temperature of the cooled zone).

[0027] Both of these thermostat methods control the compressor in response to the sensed temperature. Figure 3a shows a time profile of temperature in comparison to upper threshold temperature 24 and lower threshold temperature 23. Figure 3b shows the on/off control of the cooling mechanism, turning on when the sensed temperature rises above the higher threshold and turning off when it falls below the lower threshold. Note that the temperature overshoots/undershoots the threshold temper-

ature as a result of thermal capacities and lags inherent in the system.

[0028] Figure 4 shows a switching cycle where the thermal conditions require more cooling effect e.g. as a result of higher ambient temperature around the apparatus, or warm items placed in the cooled zone. Because of the larger amount of heat applied to the cooled zone, its temperature rises more quickly when the cooling mechanism is not running. When the mechanism is running, the temperature falls, but more slowly than shown in Figure 3 because the net rate of heat removal is lower because the increased rate heat applied to the zone balances more of the rate at which the cooling mechanism removes heat. The consequence is that the off-period is shorter and the on-period longer. So, the increased rate of heat applied to the cooled zone affects the on- and off-periods and, particularly, the proportion of overall time that the cooling mechanism is running. This "proportion" (or "duty") is a means to adjust the overall cooling effect. 100% would be maximum effect, with the cooling operating all of the time, and 0% would be no cooling effect, with no cooling effect. The cooling effect (average heat removal rate) is not linearly related to the proportion of time running. When a cooling mechanism is started, it takes some time to establish a temperature differential, and if it is stopped early then the cooling effect is disproportionately small. At high levels of cooling rate, increased temperature differences develop (e.g. between the evaporator and the cooled zone, and between the condenser and the external environment). Increased temperature differences usually cause a reduction of heat pumped by the cooling mechanism. Between these extremes of duty, the cooling effect will be proportionally higher.

[0029] Consider the case of a particular cooling apparatus in an environment of controlled temperature. If the cooling effect is adjusted to bring the cooled zone to a particular temperature then, after a period for stabilisation, the on/off switching will converge to a particular duty with particular on and off periods. An identical apparatus under identical conditions will exhibit the same on/off characteristics. If the apparatus is modified to replace the thermostatic switch with a timer that replicates this on/off pattern then the temperature of the cooled zone will be the same. Under these conditions the temperature control performance is the same with the timer as with the thermostatic switch. A timer does not respond to changes so if conditions change then the temperature of the cooled zone will change. For example the likely effects on the temperature of the cooled zone would be:

- Higher ambient temperature around the apparatus: increase
- Warm item placed in the cooled zone: increase *
- Open and close the door: increase *
- Reduction of mains voltage: increase, because the cooling mechanism is less effective

[0030] Note that conditions marked * are transitory, after a stabilisation period the temperature of the cooled zone will revert to its previous value even if the on/off pattern is not changed.

[0031] Consider the case of a particular design of cooling apparatus where it envisaged that a number of examples will be manufactured with only small differences between the examples. A first test is performed on an example of the design to find an on/off control pattern that gives a desired temperature in the cooled zone under particular conditions of external ambient temperature and mains supply voltage. We will refer to this as the "base condition". Then, a series of tests are performed on an example of the design under a predetermined set of ambient temperatures and a predetermined set of mains voltages to find on/off patterns for each condition that gives the same desired temperature of the cooled zone. These patterns will be different from the base condition so that the cooling effect matches the different rates of heat applied to the cooled zone. Preferably, the patterns are changed in a predetermined way in response to a "cooling effect parameter", for example as shown in Figure 5. Curve T_{on} represents the duration of the on-period of the cooling mechanism and curve T_{cycle} represents the sum of T_{on} and T_{off} (the duration of the off-period). At maximum value of the parameter, $T_{on} = T_{cycle}$, so $T_{off} = 0$, hence the cooling is running continuously. As the parameter is decreased, T_{on} decreases and T_{off} increases from zero to reduce the cooling effect. To avoid poor cooling efficiency at low values of the parameter, below a parameter threshold of P_{th} , T_{on} is held at a minimum value but T_{off} is increased more quickly to reduce the cooling effect. So, if this "control law" is used in the series of tests, in each condition it is necessary to change only the cooling effect parameter to set a pattern that gives the desired temperature.

[0032] The relationship between external ambient temperature and necessary cooling effect parameter (to achieve the desired temperature) will be progressive, higher ambient will progressively require a higher parameter value. From the results of the tests, this relationship can be characterised mathematically. Likewise, the relationship between mains voltage and required parameter can be characterised mathematically. There could be some interaction between ambient temperature and mains voltage; if the ambient temperature is higher then the sensitivity to mains voltage may be increased. This can also be characterised by a more sophisticated mathematical model, yielding the necessary cooling effect parameter from both the mains voltage variable and the ambient temperature variable. A convenient mathematical model is to hold a series of combinations (points) of mains voltage, ambient temperature and necessary cooling effect parameter. In a new situation, the necessary cooling effect parameter is found from the prevailing mains voltage and ambient temperature conditions by interpolating between nearby points in the series.

[0033] Described here is a method to control temper-

ature of the cooled zone, compensating for the effects of mains voltage and ambient temperature. Clearly it would be possible to control only on the basis of one of these (for example, only mains voltage) in which case changes other would not be taken into account and could cause larger deviations of the cooled zone temperature from the desired temperature.

[0034] If the door of the cooled zone is opened then there will be a temporary increase of the temperature inside the cooled zone. In a separate series of tests on an example cooling apparatus of a particular design it is possible to characterise this temperature increase. In particular, a time variation of the cooling effect parameter may be found that counteracts the increase in temperature to minimise the disturbance of temperature. The effect of opening the door can, of course, be variable as a result of different duration for which the door is open and different external ambient temperature. These effects can be characterised in more sophisticated tests on an example apparatus by testing the effect of door openings of different durations, and under conditions of different external ambient temperature. More particularly, the necessary time variation of cooling effect parameter to counteract the temperature deviation can be found for different combinations of door open time and external ambient temperature. So, in a similar way to managing the long-term average temperature in response to mains voltage and/or external ambient temperature, short-term deviations as a result of opening the door can be managed according to a mathematical model of the necessary time variation of cooling effect parameter - based on door open time and/or external ambient temperature.

[0035] In typical use of a cooling apparatus, another significant effect on the temperature of the cooled zone is when warm item(s) are placed in the zone. If they are small and/or have temperature only a little different from the desired zone temperature then the deviation of zone temperature will be small and may be acceptable as it is only lasts a short time (until the items reach the zone temperature). However, the temperature deviation may become excessive if the items are large and/or are very different in temperature from the desired temperature. With gas/compressor cooling mechanisms, it is possible to detect that significantly more heat has been applied to the cooled zone by the effect on the temperature of the circulating gas and/or on the electrical conditions of the motor. Consider the situation of a cooling apparatus operating in a stabilised condition with a steady on/off cycle pattern of operation of the motor/compressor. In the part of the cycle when the compressor is running, liquefied gas is forced by the compressor into the evaporator 4 where it evaporates, absorbing heat from the cooled zone, then the evaporated gas exits the evaporator and enters the compressor at the "suction" port. In a condition of steady heat input to the cooled zone, the temperature at the exit of the evaporator will follow a time profile such as shown in Figure 8a. A short time after the compressor starts the temperature falls because cold gas from the

evaporator reaches a temperature sensing point on the gas circuit. As the compressor continues to run the temperature falls further and continues to fall for a short time after the compressor stops (due to thermal lags and reserve of liquefied gas in the evaporator etc.). Later, in the off-period, the sensed temperature rises due to the temperature difference from the ambient temperature around the sensing point. When a warm item is placed in the cooled zone this raises the temperature of the zone and this affects the temperature of the evaporator, particularly near the exit of the evaporated gas because the extra heat applied to that part of the evaporator is not counteracted by boiling of liquefied gas (which would hold the temperature at the boiling point). This warmer gas exits the evaporator and travels to the temperature sensing point on the gas circuit. So the time profile of the sensed temperature will be different, such as shown in Figure 8b. The important differences are:

- Higher average temperature
- Smaller peak-peak temperature variation

[0036] A higher heat load applied to the cooled zone will result in more significant changes to the sensed temperature profile. The effect on the time profile is not large, but the profile of the sensed gas flow temperature can be examined to detect a change which indicates that a higher heat load has been applied. Further, the detection can also take into account other factors such as:

- Occurrence of an opening door event
- Absence of any significant change in external ambient temperature
- Absence of any significant change in mains supply voltage

[0037] A decision about whether or not an additional heat load has been placed in the cooled zone can include weightings according to the degree of the above factors in addition to a degree of change of the gas temperature profile. The result is to decide whether or not a heat load has been applied, if it is decided that it has then a short-term increase of cooling parameter effect can be triggered. A series of tests can be conducted on an example cooling apparatus where typical heat loads are placed in the cooled zone and time profiles of parameter increase are found to counteract increase of temperature of the zone. A further sophistication can be to deduce an estimate of the degree of heat load from the degree of change of the sensed gas temperature profile. In this case the degree of change, optionally averaged from measurements of a small number of on/off cycles, is used to select an appropriate time profile of increased cooling effect parameter. Again, the appropriate profiles can be characterised from tests on an example apparatus, being subjected to a range of increased heat loads.

[0038] When a heat load is applied to a cooling apparatus that uses a gas/motor/compressor cooling mechanism,

the change in gas conditions increases the load on the compressor and this is reflected in the electrical conditions of the motor. In particular, for single-phase induction motors, the current taken by the main winding increases and more particularly the power taken (i.e. including the effect of relative phase between voltage and current) increases. Additionally or alternatively the voltage induced in an auxiliary winding is also affected by the additional load, typically showing as a reduction of amplitude and/or change of phase. These parameters can be used to detect a transient increase of heat load in a similar way to the temperature profile of the gas exiting the evaporator as described previously. Likewise, a short-term increase in cooling effect parameter can be triggered to counteract the increase of temperature of the cooled zone.

[0039] Temperature of the cooled zone is affected by many variables, including those described above (external ambient temperature, mains voltage, door opening etc.). Other variables are associated with the particular example of the cooling apparatus, such as:

- Thickness and quality of the thermal insulation around the cooled zone
- Tolerances of the cooling mechanism such as quantity of gas in the cooling circuit, thickness and number of turns of wire in the motor, variation of gap between the motor rotor and stator, friction in the motor or pump etc.

[0040] If the temperature management is based on the characteristics of one example of a design then tolerances of other examples of the design could result in variation to temperature of the cooled zone. These can be corrected (wholly or partly) by one or more adjustments of each example. E.g. an example of a design can be tested and characterised in an extensive series of tests. Then this characterisation can be applied as a base characterisation to individual examples. These can then be tested in a further, reduced series of tests or even a single test and adjustment(s) made to correct for the small differences of each example from the base characterisation. Preferably each example apparatus is operated in a steady state at a particular mains voltage. The average temperature in the cooled zone is measured and a calculation performed on it, optionally also including the prevailing ambient temperature, to devise an improved control law which can then be applied to the example apparatus.

[0041] It is common for refrigeration appliances to have a user control to vary the temperature of the cooled zone. In the case of a control system without a sensor in the cooled zone, a user control can also be provided to adjust the control law to change the temperature of the zone. This is another way in which the tolerances between different examples can be accommodated, by the user making appropriate adjustments to the user control.

[0042] Illustrated in figure 6 is a cooling apparatus

where the temperature control system is integrated with the thermoelectric motorcompressor control 8 (see Fig. 1) to make a thermal control 25, optionally mounted on the side of the compressor. Thermal control 25 optionally includes facilities to:

- sense mains voltage and/or
- sense an ambient temperature local to the control, via sensor 26, and/or
- sense a gas flow temperature, via sensor 40, and/or
- sense opening/closing of the door
- accept a user adjustment, via control 38
- sense electrical conditions of the motor

[0043] Figure 7 is a diagrammatic representation of thermal control 25, applied to the example of a cooling mechanism using a motorcompressor (but could be applied to other types of cooling mechanisms). Electrical power from supply connections 31 and 32 is applied to the Motor 27 of the motorcompressor and controlled by one or more switches such as 29 and 30, for example for "main" and "auxiliary" windings of induction motors commonly used for small cooling apparatus. Thermal control 25 may also include thermoelectric overload protector 28 and other components associated with starting and running the motor (e.g. run capacitor and starting PTC (a thermistor with a positive temperature coefficient) - not shown in Figure 7). Switch(es) to control the motor are operated by electronic circuit 33 which optionally has:

- Input signal 34 from ambient temperature sensor 26
- Mains supply via connections 35a and 35b
- Input signal 41 from gas circuit temperature sensor 40
- Input signal 39 from user control 38
- Door open/close signal 42 from door switch 17
- Motor current signal 44 from current sensor 43 (e.g. resistor or current transformer)
- Input signal 45 representative of motor auxiliary winding voltage

[0044] The ambient temperature sensor 26 is most economically integrated with the control 25 but if this is adjacent to a motorcompressor or other heated/cooled parts it may give less effective control of the temperature of the cooled zone. Preferably the sensor is located a small distance from such parts, either by separation from the control 25 or by shaping of the housing of the control with the sensor located at an extremity. Alternatively, the control 25 may be located in the cooling apparatus away from heated/cooled parts.

[0045] Likewise, the user control 38 can be integrated with the control 25 but this may be inconvenient to users. Optionally it may be put in a more convenient location (eg. Like control 22 in Figure 2), connecting to the control 25 by a cable. Alternatively, the entire control 25 may be located more conveniently, such as for control 21 in Figure 2. In this case, an ambient temperature sensor could

be integrated with the control without adverse sensing effects from any nearby hot/cold parts. Additionally, such a location can be selected to reduce the incidence of humidity which can cause degradation and fault in the control.

[0046] Circuit 33, which may be embodied as a micro-controller and/or discrete components and/or dedicated analog/digital integrated circuits provides a control characteristic according to any of the characteristics described previously, responding to inputs provided in the particular embodiment. For example:

Timer only: The control 25 operates the motorcompressor according to a preset on/off cycle pattern. Optionally, a user control can be included to allow adjustment of the pattern preferably by varying the on-period. Other control methods, such as described below, may revert to this method (as a fail-safe) if a fault, malfunction or extreme condition is detected in the signals from other sensors and other inputs. Preferably, more extensive faults should result in the cooling system running continuously, rather than providing inadequate cooling action.

Responsive to ambient temperature: The control 25 operates the motorcompressor in an on/off cycle where the durations of the on- and off-periods responds to the sensed ambient temperature and, optionally, a user control.

Responsive to ambient temperature: mains voltage and door opening: Inputs 34, 35a, 35b and 42 are used by the control circuit to vary the on/off pattern to counteract long-term temperature deviations from desired temperature caused by ambient temperature or mains voltage and to counteract short-term deviations caused by opening of the door.

Responsive to gas circuit temperature: In combination with any of the above the control circuit 33 responds to a change in the temperature profile, sensed via signal 41, and triggers a short-term change of on/off pattern to counteract temperature deviation induced by transient heat load to the cooled zone

Responsive to motor electrical conditions: In combination with any of the above the control circuit 33 responds to a change in the electrical conditions of the motor, sensed via signals 44 and/or 45, and triggers a short-term change of on/off pattern to counteract temperature deviation induced by transient heat load to the cooled zone.

[0047] Other combinations of control methods will be evident to the skilled person.

[0048] Other features may also be included in control 25. A particular requirement for refrigerators and coolers

is to avoid accumulation of ice on the evaporator in the cooled zone. In conditions of high duty (for example when the external ambient temperature is high), the temperature of the evaporator may not rise above the melting point of ice. Preferably a feature is included in the control circuit 33 that detects the condition of high duty (e.g. over 30%) over a long period (e.g. longer than 12 or 24 hours). If this condition is detected the control preferably responds by stopping the cooling mechanism for a preset time, sufficient to ensure that the ice melts and the water runs to waste. A time such as 30 minutes may be sufficient but this can be characterised from tests on an example of the design of apparatus. In conditions of very high ambient a shorter time may be acceptable and this can be characterised in further tests. In operation, the control 25 preferably stops the cooling mechanism for a time that varies inversely with the sensed ambient temperature because this assures melting of the ice but reduces the deviation of temperature of the cooled zone. The appropriate stop-time/ambient temperature characteristic is taken from the tests of an example apparatus. [0049] No doubt many other effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the spirit and scope of the claims appended hereto.

Claims

1. A refrigerator comprising:

a thermally insulated cooled zone having a door to enable a user to access said cooled zone;
 a cooling system to cool said cooled zone;
 a control unit coupled to control said cooling system; and
 a temperature sensor coupled to said control unit, wherein said temperature sensor is outside said cooled zone to sense an ambient temperature of said refrigerator;
 wherein said control unit stores apparatus characterising data characterising a relationship between a pattern of operation of said cooling system and a temperature of said cooled zone for a plurality of different said ambient temperatures, and
 wherein said control unit is configured to control a said pattern of operation of said cooling system responsive to said sensed temperature and said stored apparatus characterising data to adjust said temperature of said cooled zone towards a target said temperature of said cooled zone.

2. A refrigerator as claimed in claim 1 wherein said cooling system is a mains electricity supply powered cooling system, the refrigerator further comprising a

mains voltage sensor, coupled to said control unit, to sense a voltage of said mains electricity supply, wherein said apparatus characterising data further characterises a relationship between said temperature of said cooled zone and said mains voltage, and wherein said control unit is further configured to control said pattern of operation of said cooling system responsive to a combination of said sensed voltage and said stored apparatus characterising data to adjust said temperature of said cooled zone towards said target temperature of said cooled zone.

3. A refrigerator as claimed in claim 1 or 2 further comprising a door sensor, coupled to said control unit, to sense operation of said door, wherein said apparatus characterising data further characterises a relationship between said temperature of said cooled zone and a duration for which said door is open, and wherein said control unit is configured to control said pattern of operation of said cooling system responsive to said sensed operation of said door and said stored apparatus characterising data to adjust said temperature of said cooled zone towards said target temperature of said cooled zone.

4. A refrigerator as claimed in claim 3 wherein said apparatus characterising data further characterises a relationship between said temperature of said cooled zone and a combination of said duration and a said ambient temperature for a plurality of different said ambient temperatures, and wherein said control unit is configured to control said pattern of operation of said cooling system responsive to a combination of said sensed duration and said sensed ambient temperature.

5. A refrigerator as claimed in any preceding claim further comprising a sensor, coupled to said control unit, to sense from outside said cooled zone an input of heat energy into said cooled zone, and wherein said control unit is configured, responsive to identification of said heat energy input, to control said cooling system to temporarily provide increased cooling of said cooled zone.

6. A refrigerator as claimed in claim 5 wherein said sensor to sense said heat energy input comprises a temperature sensor configured to sense a temperature of a gas in a portion of a gas circuit of said cooling system in a return path from said cooled zone towards a compressor of said cooling system.

7. A refrigerator as claimed in claim 6 wherein said control unit is configured to determine one or both of a time average of said temperature of said gas and a peak-to-peak variation in said temperature of said gas to identify said input of heat energy into said cooled zone.

8. A refrigerator as claimed in claim 5, 6, or 7 wherein said sensor to sense said heat energy input comprises a sensor to sense a parameter of an electrical conditions of a motor of said cooling system.

9. A refrigerator as claimed in any one of claims 5 to 8 wherein said control unit is configured to identify said input of heat energy responsive to a combination of said sensed heat energy input and one or more of: detection of opening of said door, absence of detection greater than a threshold change in said sensed ambient temperature, and absence of detection of greater than a threshold change in a voltage of a mains power supply for said cooling system.

10. A refrigerator as claimed in any preceding claim wherein said control unit is configured to determine a value of a cooling effect parameter from said sensed ambient temperature and said stored apparatus characterising data, and to determine durations of on and off periods of said cooling system responsive to said value of said cooling effect parameter to control said pattern of operation of said cooling system.

11. A refrigerator as claimed in claim 11 wherein said on and off period durations vary with said value of said cooling effect parameter such that as said cooling effect parameter changes said on period duration reduces whilst a duration of an on-off cycle of said pattern of operation remains substantially constant, until a minimum value of said on period duration is reached when said on period duration remains substantially constant and said duration of on-off cycle increases.

12. A refrigerator comprising:

a thermally insulated cooled zone having a door to enable a user to access said cooled zone;
a cooling system to cool said cooled zone;
a control unit coupled to control said cooling system; and

a sensor, coupled to said control unit, to sense a voltage of a mains power supply to said cooling system;

wherein said control unit stores apparatus characterising data characterising a relationship between a pattern of operation of said cooling system and a temperature of said cooled zone for a plurality of different said voltages of said mains power supply; and

wherein said control unit is configured to control a said pattern of operation of said cooling system responsive to said sensed voltage and said stored apparatus characterising data to adjust said temperature of said cooled zone towards a target said temperature of said cooled zone.

13. A method of controlling the internal temperature of cooling apparatus comprising a thermally insulated cooled zone without using a temperature sensor inside said cooled zone, the method comprising:

characterising a relationship between a temperature of said cooled zone, a pattern of operation of a cooling system for said cooled zone, and one or both of an ambient temperature of said cooling apparatus and a voltage of a mains power supply to said cooling system;
measuring one or both of said ambient temperature and said mains power supply voltage; and
using said relationship to control said pattern of operation in response to said measured ambient temperature/mains power supply voltage to adjust an internal temperature of said cooled zone towards a target temperature without measuring said internal temperature of said cooled zone.

14. Cooling apparatus comprising:

a thermally insulated cooled zone without a temperature sensor inside said cooled zone;
data characterising a relationship between a temperature of said cooled zone, a pattern of operation of a cooling system for said cooled zone, and one or both of an ambient temperature of said cooling apparatus and a voltage of a mains power supply to said cooling system;
means for measuring one or both of said ambient temperature and said mains power supply voltage; and
means for using said relationship to control said pattern of operation in response to said measured ambient temperature/mains power supply voltage to adjust an internal temperature of said cooled zone towards a target temperature without measuring said internal temperature of said cooled zone.

15. A refrigerator comprising:

a thermally insulated cooled zone having a door to enable a user to access said cooled zone, and without a temperature sensor inside said cooled zone;

a cooling system to cool said cooled zone;
a control unit coupled to control said cooling system; and

a user control coupled to said control unit;
wherein said control unit is configured to control a cyclical pattern of on-off operation of said cooling system, and is responsive to said user control to adjust a duty cycle of said on-off operation; in particular

wherein said control unit is responsive to said user control to adjust a duration of an on-period

of said cooling system operation duty cycle.

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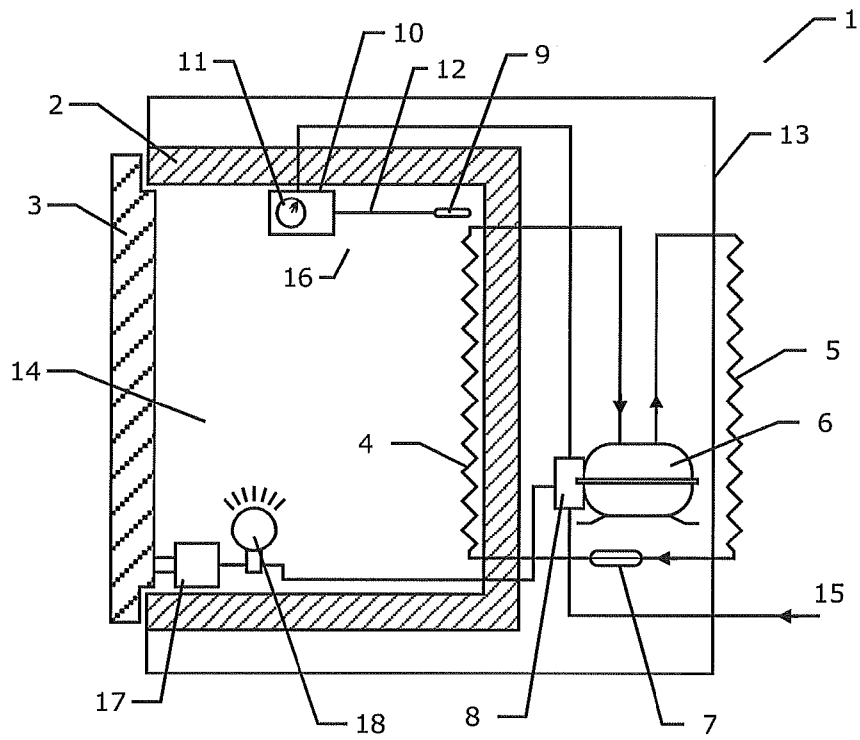


Fig 1

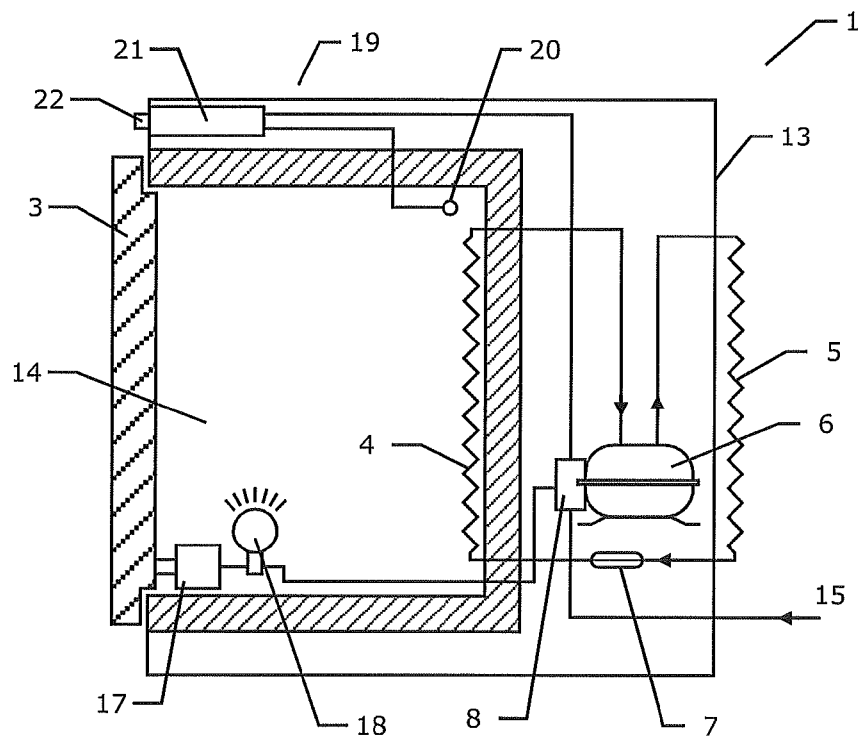


Fig 2

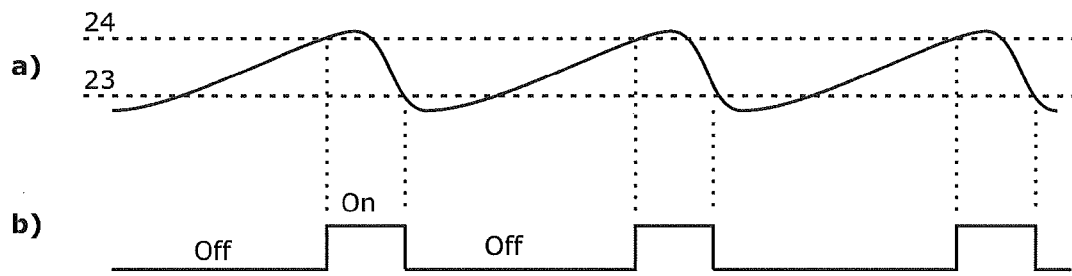


Fig 3

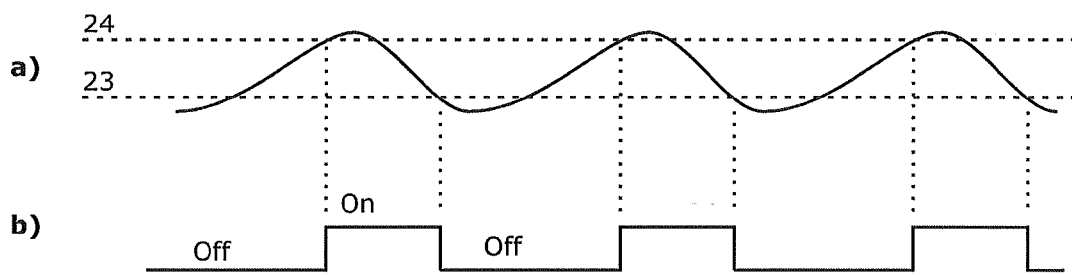


Fig 4

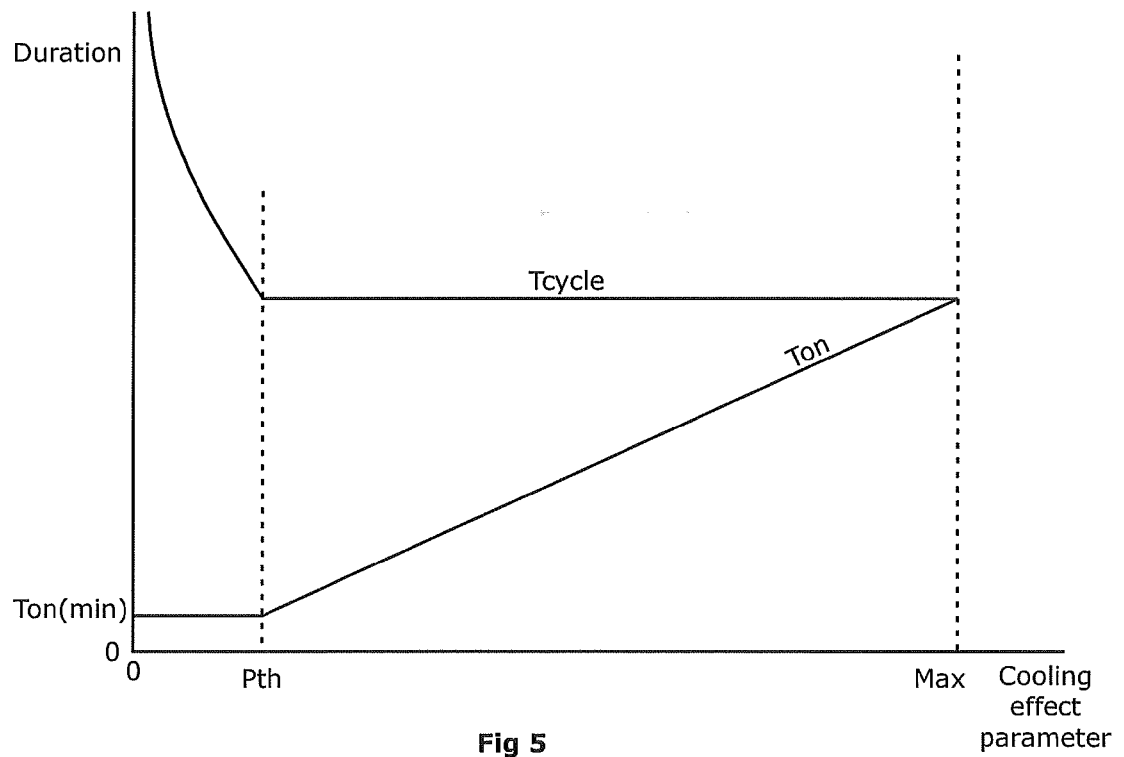


Fig 5

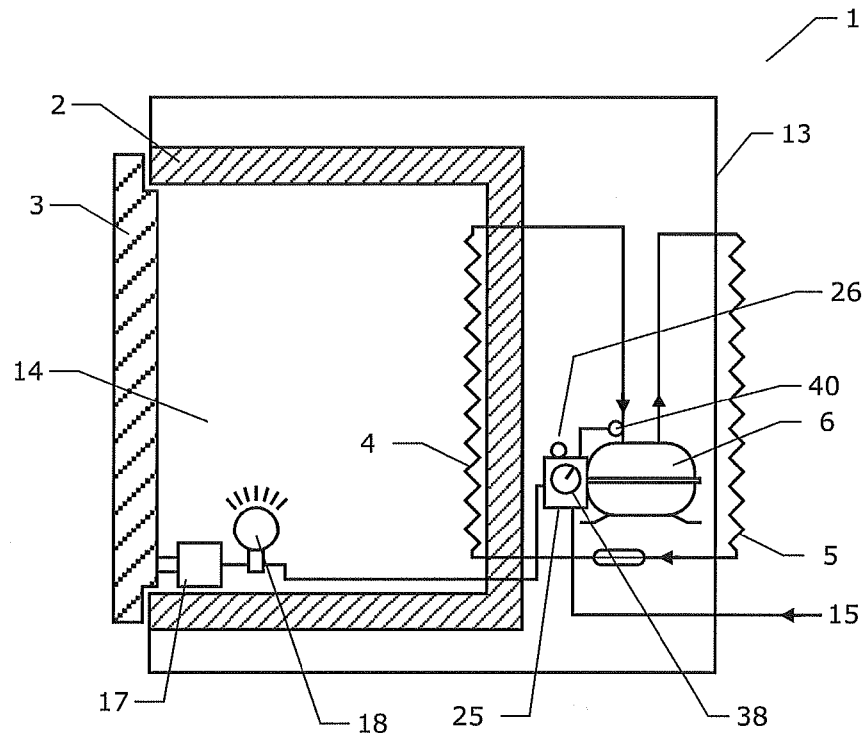


Fig 6

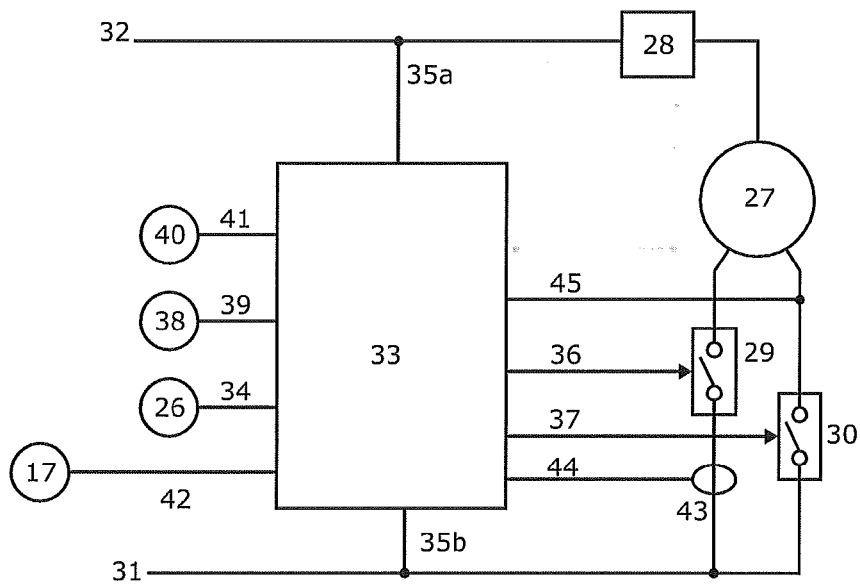


Fig 7

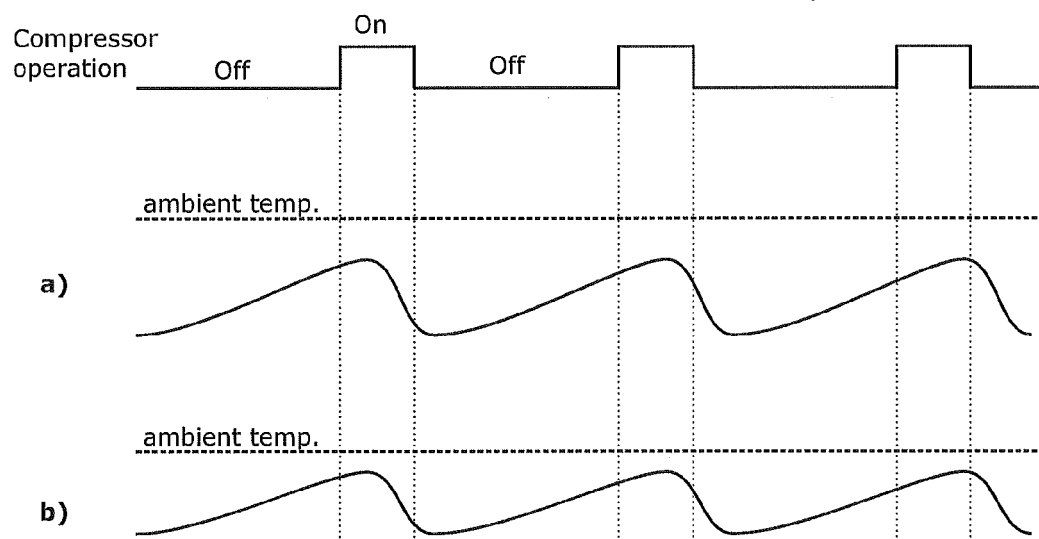


Fig 8