AGROTECHNOLOGY & FOOD SCIENCES GROUP
WAGENINGEN UR

Reefer units guide for flowerbulb shipment (version 1.1)

Dr. Leo Lukasse, Ir. Janneke de Kramer-Cuppen

AFSG Report number 808

Colophon

This project was supported by:

NIEBERDING VERZEKERINGEN BV
Postbus 37, 2180 AA Hillegom
Molenhoeve 17
2182 EZ Hillegom
Telefoon: 0252 - 531626
Telefax : 0252 - 531726
Internet : www.nieberding.nl
E-mail : info@nieberding.nl

VELDBOER AGREX B.V.
Agrarische Expertise
Wierweg 27
1774 NJ Slootdorp
E-mail: veldboeragrex@planet.nl
Tel. : 0227 - 58 14 17
Fax : 0227 - 58 12 83
Mobiel : 06 - 51 49 03 40
VRT registertaxateur agrarisch, specialisme Sierteelt en Tuinbouw
Lid NVAE Nederlandse Vereniging van Agrarische Experts

K-SERVICES
MARINE & CARGO SURVEYORS - CONSULTANTS--NAVAL ARCHITECTS
Phone: +1-9085128215
Email: yiannis@comcast.net
Website: www.ship.gr/K-Services

Title	Reefer units guide for flowerbulb shipment (version 1.1)
Author(s)	Dr. Leo Lukasse, Ir. Janneke de Kramer-Cuppen
AFSG number	808
ISBN	978-90-8585-136-3
Date of publication	June 2007
Confidentiality	no
OPD code	07/055
Approved by	Ir. H.L.M.M. Maas MBA

Agrotechnology and Food Sciences Group
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 475 024
E-mail: info.afsg@wur.nl
Internet: www.afsg.wur.nl, www.reefertransport.nl

The quality management system of Agrotechnology and Food Sciences Group is certified by SGS International Certification Services EESV according to ISO 9001:2000.

Preface

This manual was composed in a project financed by Nieberding Verzekeringen B.V. Purpose of the project was to provide flowerbulb shippers with information and/or tools to support them in deciding on their reefer unit settings. Aspects covered are temperature, fresh air vents, defrost interval, relative humidity, dehumidification, bulb mode, fan speed, defrost termination temperature, the Mollier diagram, a flowerbulb shipper's checklist and some internet links on (the use of) reefer containers. There are three outputs of the project:

1. This manual.
2. Shipper's check list for flowerbulb shipment in reefer containers: a check list of one A4 form covering the most important issues which deserve the flowerbulb shipper's attention during loading of containers (also included in this manual as appendix IV, p. 22).
3. Reefer Settings Support Tool for Flowerbulbs: an excel program that advises on reefer unit settings. Input to the program is some information on desired climate, destination and main unit capacities. Output is a list of advised unit settings and an indication of the feasibility of the desired climate.

Content

1 Introduction

This reefer unit guide discusses the unit settings relevant to flower bulb transport in reefer containers. A reefer container (Fig. 1) consists of a 20 or 40 ft box with T-bar floor and a refrigeration unit. The box is loaded with palletized crates. The refrigeration unit is equipped with fans that draw warm air from the headspace (above the pallets) and push the cooled air back into the box, through the T-bar floor.

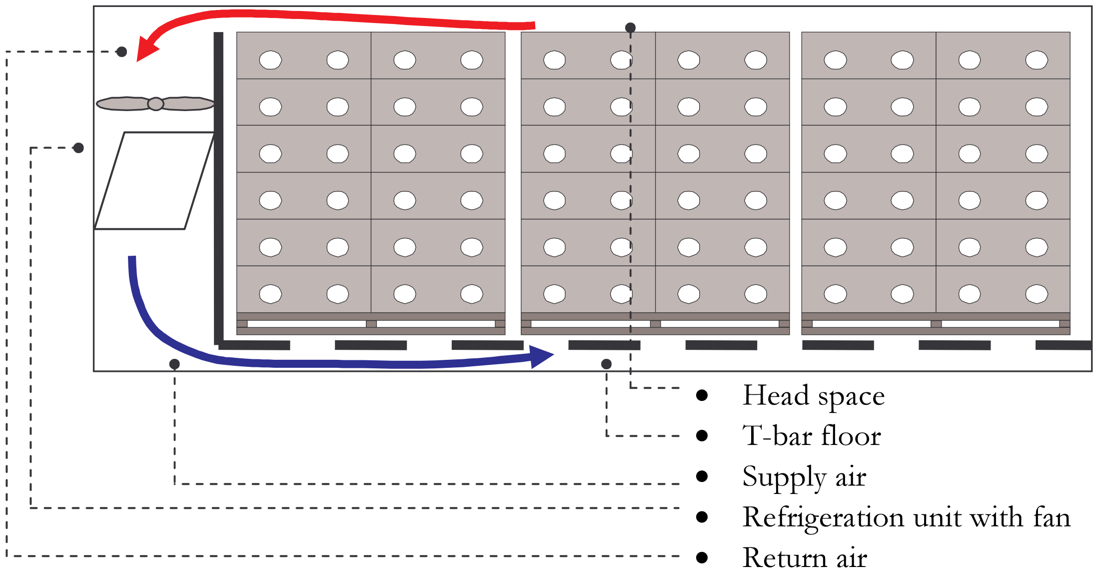


Fig. 1, schematic overview of a reefer container

Many factors affect the bulb quality at delivery (Fig. 2). However, the scope of this study is limited to relating unit settings to the climate in the container.

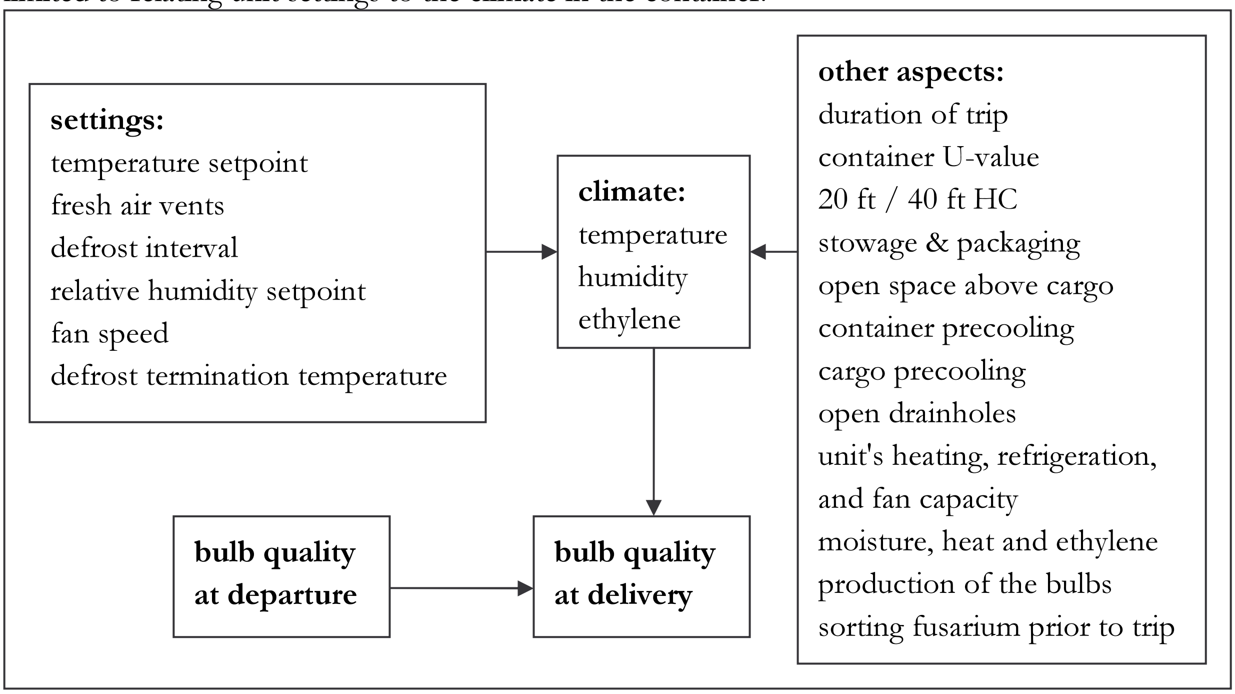


Fig. 2, schematic overview of factors affecting bulb quality at delivery.

1.1 Climate aspects important to flower bulbs

Climate aspects important to flower bulbs are temperature, relative humidity (RH) and ethylene. It depends on the species, cultivar and stage of life which aspect is most important in a specific shipment. Some broad categories are indicated in Table 1.

Table 1, bulb categories, typical temperatures and important aspects.

bulb species	temperature	important aspects
lily	-2 ~ +2 °C	temperature
tulip	+5 ~ +22 °C	temperature, ethylene, RH (60 ~ 75%)
perennials	-1.5 ~ 0 °C	temperature
others	+1.5 ~ +30 °C	often temperature and RH (60 ~ 75%)

An ATO certified reefer container meets some standards that allow for a good climate control in the container. The standards especially apply to the aspects of temperature and ethylene (Table 1). The requirements for ATO certification are:

1. Air ventilation of empty container (at 400V/50Hz) at least 2.6 m^3/h per m^3 internal container volume.
2. Air circulation inside empty container (at 400V/50Hz) at least 40 m^3/h per m^3 internal container volume.
3. Height of T-bars in 40 ft. containers at least 60 mm, in 20 ft. containers at least 30 mm.
4. Four drainholes in the corners.

ATO certification yields a quality assurance on aspects not covered in other standards or certification schemes. For more details on ATO certification visit www.reefertransport.nl. Unfortunately, with improper unit settings flowerbulbs can be perished, even in ATO certified reefers. This reefer units guide explains the relation between reefer unit settings and the container climate.

1.2 Overview of possible unit settings

Table 2 lists the possible unit settings and their usual ranges. RH control through dehumidification (Table 2) is optional on all reefer units nowadays. 'Optional' means: the units are manufactured in such a way that the dehumidification option *may* easily be installed. The dehumidification option is installed indeed on a vast number of units, *but not on all units.*

Table 2, possible reefer unit settings and their usual ranges

issue no.	setting	range
1	temperature	- 30.0 ~ +30.0 °C
2	fresh air vents	0 ~ 200 m^3/h (CMH) @ 60 Hz
3	defrost interval	3, 6, 9, 12, 24 h, AUTO or OFF
4	RH (dehumidification)	60 ~ 95% or OFF
5	if (bulb mode 'on') then: • RH setp. range • fan speed • defrost termination temperature	 • 60 ~ 95% or OFF • alt [default], hi, lo • +4.0 ~ +25.6 °C

1.3 Outline of this manual

In the remainder of this manual chapter 2 through 6 each discuss one of the settings in Table 2. Chapter 7 lists the unit settings affecting the climate, and their possible ranges, more specifically per unit manufacturer (Table 5 till Table 7). Appendix I and II (p. 18 and 20) provide some background calculations. Appendix III (p. 21) contains a Mollier diagram, also named h/x diagram or psychrometric chart. The Mollier diagram is widely accepted as a standard for graphically depicting the mutual relations between dry bulb temperature, wet bulb temperature, dewpoint temperature, relative humidity, absolute humidity, enthalpy content and density of humid air. Appendix IV (p. 22) presents a flowerbulb shipper's checklist for flowerbulb shipment in reefer containers. Finally appendix V (p. 23) is a collection of internet links that may be worthwhile for the flowerbulb shipper who wants to gain some more insight in the use of reefer containers.

2 Temperature

For all units the temperature (issue no. 1 in Table 2) may be set in the range from -30.0 ~ +25.0 °C. For most in the range -30.0 ~ +30.0 °C. For some even in the range -35.0 ~ +30.0 °C. In perishable mode (set temperatures above -5.0 °C) supply air temperature (Fig. 1) will be tightly controlled to the set temperature. The return air temperature usually is 0.5 to 1.0 °C warmer than supply air temperature. With fans running at high speed the warmest spots in the container do not need to be more than about 1.5 °C above supply air temperature. Cargo temperatures below set temperature are only to be expected when the ambient temperatures drop far below the set temperature. This may esp. occur during inland transport at the US east coast in winter.

3 Fresh air vents

Fig. 3, some of the most common fresh air vents (from left to right Carrier, Thermo King, Daikin).

Fresh air vents (issue no. 2 in Table 2), or simply vents, are to be closed, unless ethylene or CO_2 is expected to reach unacceptable levels. In flowerbulb shipments ventilation is primarily used to reduce the risk of ethylene damage in tulip bulb shipments. The more one ventilates the lower the ethylene level in the container. Fusarium-infected tulip bulbs (Fig. 4) produce a lot of ethylene. The percentage of possibly infected bulbs is unknown, but heavily depends on thorough sorting prior to shipment. Ethylene damage causes poor or no flowering later on. Extra complication: damage due to ethylene is only visible when the bulbs start flowering.

Fig. 4, fusarium-infected tulip bulbs.

Main drawback of ventilation is that the container takes in humidity present in the ambient fresh air. This increased humidity intake has two adverse effects:

1. increased need for defrosting at setpoints below +10 °C.
2. a small (?) increase of the relative humidity inside the container.

The first effect is the most significant. Increased defrost effort causes more frequent or longer periods without cooling, and defrost heat leaking into the cargo hold through the return air opening. Thus increasing the defrost need decreases temperature stability. Esp. for highly temperature-sensitive cargo (lily bulbs) this effect may be detrimental. The second effect, an increased relative humidity inside the container, may give rise to penicillium (mould) growth, which may damage the bulbs. This kind of damage is immediately visible at arrival.

The amount of water that enters (or leaves) the container through ventilation depends upon the ventilation setting and the difference between the (absolute) humidity inside and outside the container, see appendix II (p. 20) for a calculation example. See Table 3 for the typical ambient humidity a container encounters during a trip over the oceans. Note: large deviation may occur during inland transport from port of arrival to final destination. This is esp. true at the US East Coast due to the continental climate overthere. For more details visit the interactive website from the Climate Diagnostics Centre (http://www.cdc.noaa.gov/cgi-bin/Composites/printpage.pl).

Table 3, expected warmest and most humid climates flowerbulbs will pass when travelling over the oceans from the Netherlands to the U.S. or Far East.

Destination	ambient temperature (°C)	ambient humidity (g/kg)
US East Coast	+12	8
US West Coast	+27	20
Far East	+27	20

Fig. 5 illustrates what happens to the steady state ethylene level [ppb] and the water intake [(kg water)/h] as a function of ventilation rate [m^3/h] for an imaginary cargo producing ethylene at a rate of 5 ml/h and ambient humidity 20 g/kg. Clearly the first 20 m^3/h of fresh air has far more effect on ethylene then the next 20 m^3/h, while water intake depends linearly on ventilation rate.

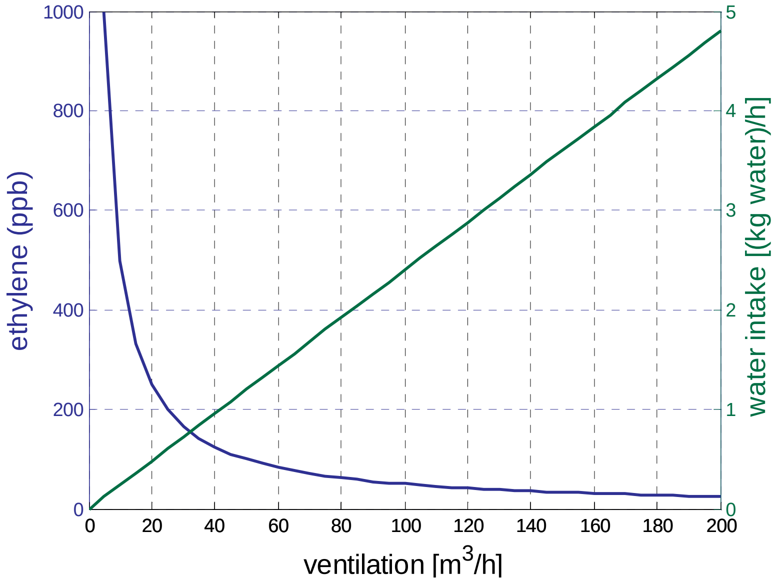


Fig. 5, ethylene and water intake as a function of fresh air exchange.

The exact amount of ventilation achieved is often uncertain because:

1. The amount of ventilation depends on the amount of ice that has been built-up on the evaporator coil. Ventilation increases when more ice builds up. So ventilation interferes with defrost interval.
2. A defrost may take about 30 minutes. During a defrost there is no ventilation.
3. The amount of ventilation depends on fan speed. Low instead of high fan speed reduces ventilation rate with about 50%.
4. The scale on the vent lid is approximate. It is designed for high fan speed, no ice on the evaporator coil and unit running at 60Hz.
5. Power supply (50 or 60 Hz)

4 Defrost interval

When the evaporator coil temperature is below 0 °C, water vapor freezes on the coil. The ice reduces air circulation rate and refrigeration capacity. Hence periodic defrosting is required to remove the ice. During a defrost refrigeration and fans stop and the coil is heated to melt off the ice. The melted ice falls in to a tray, called drain pan, and is drained off to the outside through a tube with S-trap.

In the past the defrost interval (issue no. 3 in Table 2) needed to be set manually. Nowadays auto-defrost is becoming available, where artificial intelligence adjusts the defrost interval depending on the need for defrosting sensed. Thermo King's Magnum units solely rely on auto-defrost, while Carrier's new units all offer the choice between auto-defrost or a user-selectable fixed defrost interval.

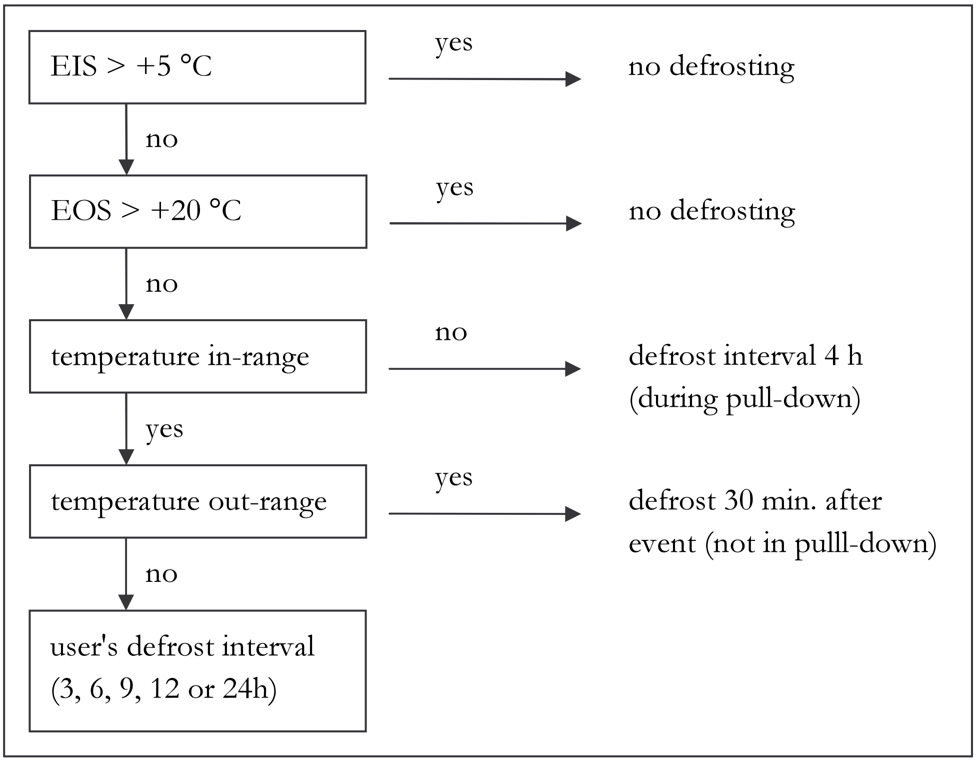


Fig. 6, defrost control logic (Daikin). EIS = Evaporator Inlet pipe temperature Sensor. EOS = Evaporator Outlet pipe temperature Sensor.

Fig. 6 shows the defrost control logic for a Daikin unit. The user's defrost interval is the primary trigger for defrosting, but it is encircled with several built-in safety rules. Basically, similar schemes hold for the other unit manufacturers.

Defrosting is required for trips with temperature setpoints below +10 °C, as the evaporator coil temperature may become approximately 10 °C lower than temperature setpoint. The required defrost interval is a function of water vapour transport to the evaporator coil. The water has two sources:

1. water evaporating from the cargo
2. (warm) ambient air entering the container for ventilation

If the bulbs are well-dried before shipment then water evaporation from the cargo is minimal.

Defrost issues to bear in mind: one defrost takes about 30 min. (at least). During a defrost there is no refrigeration, no air circulation, no air ventilation, and defrost heat flows into the container through the return air opening.

The “reefer settings support tool” , published along with this manual, can be used to select a suitable defrost interval. The underlying calculation is shown in appendix II (chapter 9, p. 20).

5 RH (dehumidification)

Relative humidity (issue no. 4 in Table 2), abbreviated to RH, in a reefer depends on the temperature setpoint, ambient conditions, amount of ventilation, cooling effort and moisture production by the bulbs. Moisture is removed by condensing or frosting and subsequent defrosting the evaporator coil. Usually in reefer containers without dehumidification RH will be higher than 90%. If a lower RH is required for a shipment, one needs to select a reefer with the dehumidification option.

If a reefer unit is fitted with a humidity sensor then the unit may dehumidify to reduce the relative humidity of the air inside the container. Quantitative insight in the process of dehumidification requires some basic understanding of air psychrometrics. Search www.engineeringtoolbox.com for 'psychrometrics' for some more background information.

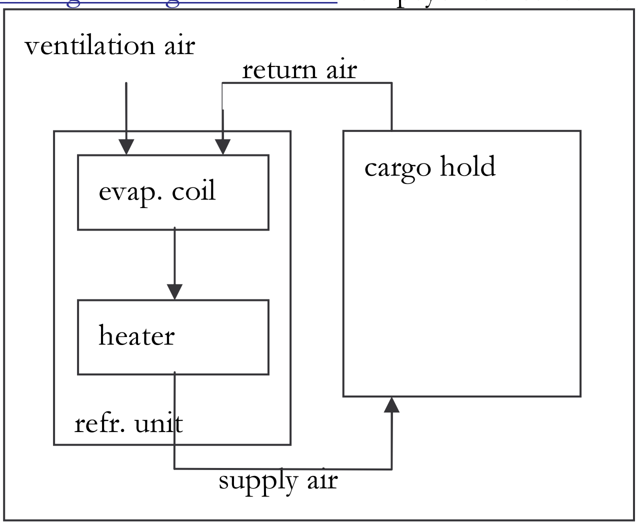


Fig. 7, schematic air flows through refrigeration unit and cargo hold

In reefer units, like in usual air conditioning units, dehumidification is performed by first subcooling the return air and subsequently reheating the air before it is supplied to the cargo hold again. See Fig. 7 for a schematic overview of the air flows through cargo hold and refrigeration unit. Suppose return air from (T, RH) = (+3 °C, 85%) needs to be conditioned to supply air of (+1 °C, 70%). Then first the air is cooled at the evaporator coil till dewpoint (vertical line down from point 1 in Fig. 8). Subsequently cooling, and thus dehumidification, proceeds (askew line towards point 2) till air leaves the evaporator coil. In that process the absolute humidity of the air is reduced from 4.0 to 2.8 g/kg (horizontal axis at the top of Fig. 8). Finally the dehumidified air is reheated to +1 °C (from point 2 to 3 in Fig. 8), before supplying it to the cargo hold.

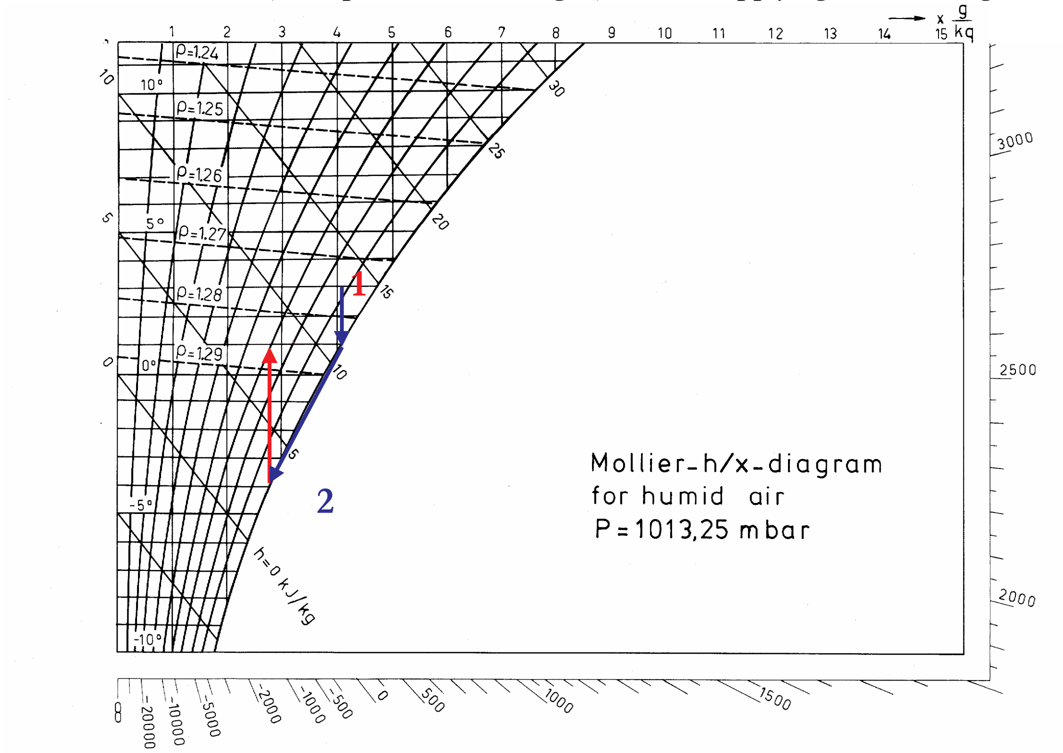


Fig. 8, Mollier diagram for humid air with dehumidification cycle depicted (1 -> 2 -> 3).

By setting an RH setpoint dehumidification is switched on to condense or freeze additional moisture on the evaporator coil and remove it during defrosts. Control of RH is usually done according to the following logics:

If (1. supply air temperature is less than 0.25 °C above temperature setpoint) and (2. RH is above RH setpoint) then
  heaters 'on'
  fan speed 'alternating'
else
  heaters 'off'
  fan speed 'high'
end

Note: Each reefer unit manufacturer has its own fan speed operation during dehumidification. When a shipper requests bulb mode 'on' then he may specify the required fan operation for any unit (see chapter 6).

Dehumidification has two adverse effects:

1. if fan speed is reduced to increase dehumidification capacity then the temperature spread in the cargo increases
2. At setpoints below +10 °C the extra ice formation on the evaporator coil necessitates more defrosting. And defrosting has negative effects on cargo temperatures (chapter 4).

Fig. 9 depicts the RH setting procedure for Daikin reefer units with a dehumidification option. For Carrier and Thermo King the procedure is very similar. If RH control is required, RH setpoint and fan speed should be specified. For Thermo King and Carrier fan speed is user-selectable only when bulb mode is 'ON'. Note that a specified RH setpoint may not be achievable. Often there is a heating capacity shortage for dehumidification which may be (partially) balanced by reducing fan speed. The lower the fan speed the lower the RH that might be reached (at the expense of increased temperature spread in the container!).

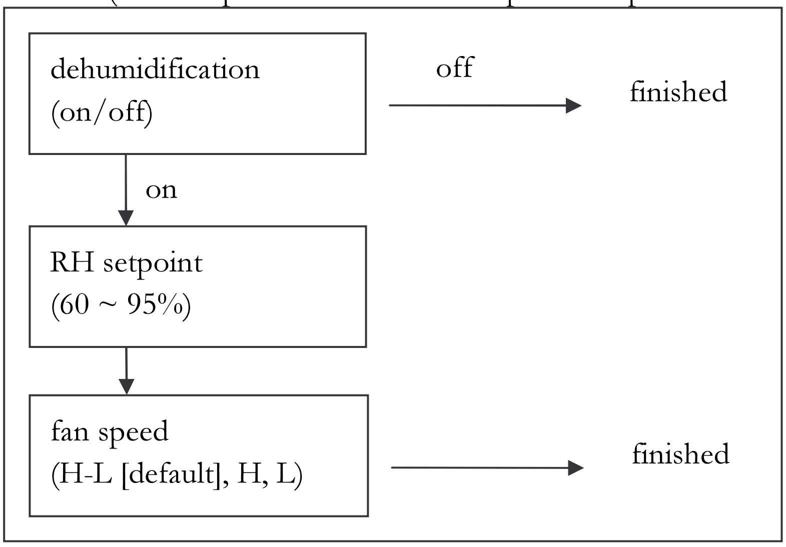


Fig. 9, dehumidification setting flow-diagram (Daikin).

Some shipping lines seem to operate Daikin reefer units where RH has a setpoint range 30 ~ 95%. It is incredible that 30% may ever be reached, but setting RH at 30% guarantees that dehumidification is active at max. capacity as much as possible. This may be attractive to shippers who just want to ship their bulbs 'as dry as possible'.

The “reefer settings support tool”, published along with this manual, can be used to check if there is sufficient heating capacity. The underlying enthalpy-content calculations are described in appendix I (p. 18). The heating capacity should be sufficient to bring air leaving the evaporator coil (Fig. 7) to the desired supply air ($T_{setpoint}$, $RH_{setpoint}$), *i.e.* to move from 2 to 3 in Fig. 8.

6 Bulb mode (defrost termination temperature)

Quite some reefers have the bulb mode option (issue no. 5 in Table 2): all Thermo King units, all PONU reefers, and some more. Reefer units with bulb mode have the same hardware as others, the sole difference is in controller software. Fig. 10 shows the bulb mode setting flow-diagram for Daikin units. For Carrier and Thermo King it is not really different. The shipper may specify bulb mode 'on/off'. If bulb mode is set to 'on', then regardless of the unit manufacturer, one gains access to two new settings:

1. fan speed (alternating, high or low).
2. defrost termination temperature.

Chapter 6.1 and 6.2 each discuss one of the above two settings.

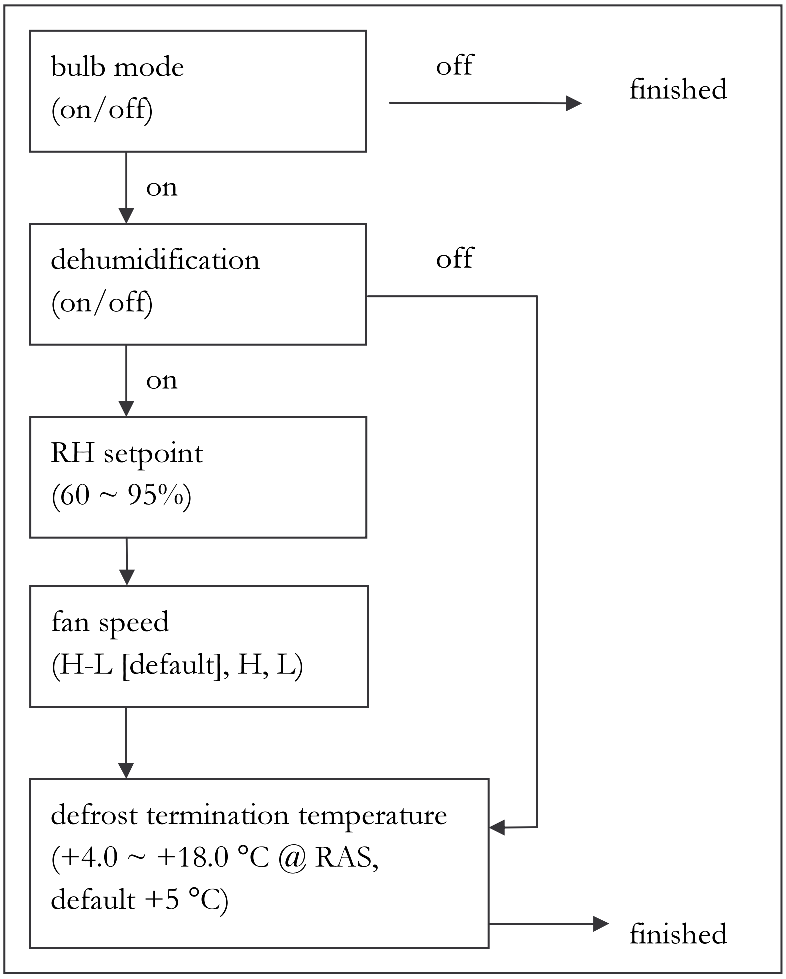


Fig. 10, Bulb mode setting flow-diagram (Daikin).

6.1 Fan speed

When a shipper specifies fan speed, he compromises between relative humidity and temperature spread. See Table 4 for some rules of thumb on how to compromise. Regardless of fan settings, supply air temperature will be neatly controlled to the set temperature. Low fan speed saves energy (and is therefore attractive for carriers), might increase temperature spread in the cargo, and does increase dehumidification capacity. Moreover low fan speed reduces the fresh air exchange (m^3/h) by 50% as compared to high speed.

Table 4, some rules of thumb for setting fan speed and fresh air vents in bulb mode.

situation	fan speed	vent setting (m^3/h)
(max. dehum. cap. required) and (cargo temperature spread of 3.0 °C is acceptable) and (less than 100 m^3/h fresh air required)	lo	200% of actually required m^3/h
{(max. allowed cargo temperature spread is 1.0 °C) or (more than 150 m^3/h fresh air required)} and (RH higher than RH setpoint is acceptable)	hi	actually required m^3/h
Other situations	alt	150% of actually required m^3/h

6.2 Defrost termination temperature

Defrost actions are terminated when the measured temperature reaches the defrost termination temperature (DTT). In bulb mode the DTT may only be *reduced* as compared to its default value when bulb mode is 'off'. For Thermo King and Carrier the DTT is compared to the measurement of the evaporator coil temperature, both when bulb mode is on and off. For Daikin DTT is compared to evap. coil temp. when bulb mode is off, but to return air sensor when bulb mode is on.

Lower defrost termination settings will result in less warming of the cargo during defrosts, but it also increases the risk of ice remaining on the evaporator coil after a defrost. If ice remains on a coil after defrosts then the (unmeasured!) widthwise supply air temperature distribution may increase unnoticed. "Why would flower bulbs require a different defrosting control than other temperature critical cargos?" is a valid question.

In preparing this document the authors met several practitioners who could tell about current practice and usual DTT settings in bulb mode: some mentioned +8.0 °C, some +5.0 °C as usual DTT setting. None of them was aware of a sound basis for those settings.

7 Reefer unit settings per manufacturer specifically.

Table 5, possible unit settings and their ranges (Daikin)

setting	Daikin LXE10E-xxx
temperature	- 30.0 ~ +30.0 °C
vents	0 ~ 190 m³/h @ 60 Hz
defrost interval	3, 6, 9, 12, 24 h
dehumidification	on/off [default]
RH	60 (some shipping lines 30) ~ 95%
if (dehum 'on') then: • fan speed • evap. coil	 • alt [default], hi, lo • hot gas in reheat coil
if (bulb mode 'on') then: • RH setp. range • fan speed • defrost termination temperature	 • 60 (some shipping lines 30) ~ 95% or OFF • alt [default], hi, lo • +4.0 ~ +18.0 °C @ Return Air Sensor (RAS), default (in bulb mode) +5 °C[1]

For Daikin bulb mode is present on PONU reefers only.

[1] *If bulb mode 'off' then defrost termination temperature is +30 °C @ Evaporator Outlet pipe temperature Sensor (EOS)*

Table 6, possible unit settings and their ranges (Thermo King)

setting	**CRR40**	**CSR40**	**Magnum**
temperature	-29.0 ~ + 29.0 °C	-29.0 ~ + 29.0 °C	- 35.0 ~ +30.0 °C
vents	0 ~ 285 m^3/h @ 60 Hz	0 ~ 285 m^3/h @ 60 Hz	0 ~ 285 m^3/h @ 60 Hz
defrost interval	AUTO (≈ 2.5 ~ 8 h[2] if ECS<+10 °C, no defrosts if ECS>+18 °C)	AUTO (≈ 2.5 ~ 8 h if ECS<+10 °C, no defrosts if ECS>+18 °C)	AUTO (≈ 2.5 ~ 8 h if ECS<+10 °C, no defrosts if ECS>+18 °C)
RH (dehumidification)	50 ~ 99% or OFF	50 ~ 99% or OFF	60 ~ 99% or OFF
if (dehum 'on') then: • fan speed • evap. coil	 • HI (economy mode LO) • 50% of area is shut off	 • HI (economy mode LO) • 50% of area is shut off	 • HI (economy mode LO) • No area shut off
if (bulb mode 'on') then: • RH setp. range • fan speed • defrost termination temperature	 • 50 ~ 99% or OFF • alt[3], hi, lo • + 4.0 ~ +30.0 [default] °C @ ECS[4]	 • 50 ~ 99% or OFF • alt, hi, lo • + 4.0 ~ +30.0 [default] °C @ ECS	 • 60 ~ 99% or OFF • alt, hi, lo • + 4.0 ~ +30.0 [default] °C @ ECS
heater operation[5]	electric, heating when RAS<(T_{setp}+0.3 °C)	electric, heating when RAS<(T_{setp}+0.3 °C)	electric, T-control range?

For Thermo King CRR40 and CSR40 units defrost terminates when ECS reaches +18 °C in frozen mode (T_{setp} < -10 °C), or +30 °C in perishable mode (T_{setp} ≥ -10 °C). For Magnum units this is +30 °C regardless of the mode.

Bulb mode is standard on all Thermo King units.

[2] *compressor operation hours instead of wall-clock hours*
[3] *Thermo King Magnum manual names 'cycle' instead of 'alt', but meaning is exactly the same*
[4] *ECS = Evaporator Coil Sensor, very similar to Carrier's Defrost Termination Sensor*
[5] *esp. of interest when lily bulbs are shipped to regions where sharp frost may occur (e.g. North-East region of US during Dec.-Febr.)*

Table 7, possible unit settings and their ranges (Carrier 69NT40-xxx-xxx)

setting	**69NT40-511-xxx**	**69NT40-531-xxx**	**69NT40-541-xxx**	**69NT40-551-xxx**
temperature	- 30.0 ~ +30.0 °C	- 30.0 ~ +30.0 °C	- 30.0 ~ +30.0 °C	- 30.0 ~ +30.0 °C
vents	0 ~ 225 m^3/h	0 ~ 225 m^3/h	0 ~ 225 m^3/h	0 ~ 225 m^3/h
defrost interval	3, 6, 9, 12 [default], 24 h[6], AUTO[7] or OFF	3, 6, 9, 12 [default], 24 h or OFF	3, 6, 9, 12 [default], 24 h, AUTO or OFF (available on some units)	3, 6, 9, 12, 24 h, AUTO [default] or OFF (available on some units)
RH (dehumidification)	65 ~ 95% or OFF	65 ~ 95% or OFF	65 ~ 95% or OFF	65 ~ 95% or OFF
if (dehum 'on') then: • fan speed	No setting. Operation: if $RH>RH_{setp}$ 'alt' else 'high'	No setting. Operation: if $RH>RH_{setp}$ 'alt' else 'high'	No setting. Operation: if $RH>RH_{setp}$ 'alt' else 'high'	No setting. Operation: if $RH>RH_{setp}$ 'alt' else 'high'
if (bulb mode 'on') then: • RH setp. range • fan speed • defrost termination temperature	• 60 ~ 95% • alt [default], hi, lo • + 4.0 ~ +25.6[8] [default] °C @ DTS[9]	• 60 ~ 95% • alt [default], hi, lo • + 4.0 ~ +25.6 [default] °C @ DTS	• 60 ~ 95% • alt [default], hi, lo • + 4.0 ~ +25.6 [default] °C @ DTS	• 60 ~ 95% • alt [default], hi, lo • + 4.0 ~ +25.6 [default] °C @ DTS
heater operation	electric, starts @ T_{setp} – 0.5 °C, stops @ T_{setp} – 0.2 °C.	electric, starts @ T_{setp} – 0.5 °C, stops @ T_{setp} – 0.2 °C.	electric, starts @ T_{setp} – 0.5 °C, stops @ T_{setp} – 0.2 °C.	electric, starts @ T_{setp} – 0.5 °C, stops @ T_{setp} – 0.2 °C.

Economy mode ON means: if $\{(T_{return} < T_{supply}+3.0\ °C)\ \&\ ((T_{setp}-0.25\ °C) < T_{supply} < (T_{setp}+0.25\ °C))\}$ then 'fans low' else 'fans high'.

For Carrier units bulb mode is an option present on units of some shipping lines only.

---

6 *compressor runtime hours instead of wall-clock hours*

7 *Carrier's auto-defrost automatically adjusts the defrost interval in the range between 3 and 24 h, with the objective to always remove a 'full ice-load' from the evap. coil.*

8 *In all Carrier units the default DTT +25.6 °C may be factory set at +18.0 °C.*

9 *Carrier uses a Defrost Temperature Sensor, mounted on the evap. coil and meant to measure the evap. coil temperature. This sensor is used for defrost termination, regardless of bulb mode on/off.*

8 Appendix I, enthalpy content calculation for dehum. capacity.

The heating capacity of a reefer unit may be insufficient to reach the desired RH setpoint. This is can be checked, using enthalpy-content calculations. The enthalpy-content of humid air is given by

$$H = T*1 + X*(2490 + 1840/1000*T)/1000 \quad (1)$$

with:

T = (dry bulb) temperature of air [°C]
X = absolute humidity of air [g/kg]

Some typical values in reefer transport are:

$T_{amb, below deck}$ = +38 °C
$T_{amb, on deck}$ = +27 °C
X_{amb} = 20 g/kg
$T_{return} = T_{setpoint}$ + 1 °C
$flow_{ventilation}$ = 10 m^3/h
$flow_{circulation}$ = 5500 m^3/h (fans high speed, 60Hz)

$$X_{return} = X_{supply} + \frac{W_{produce}}{1000 * flow_{circulation} * 1.2} \text{ [g/kg]}$$

$W_{produce}$ in [kg/h]
$P_{refrigeration}$ = 11 kW = refrigeration capacity @+2/+38, 60Hz
$P_{heating}$ = 6 kW = heating capacity @ 60Hz

Steps:

1. Calculate enthalpy content H_{amb} of the ambient (ventilation) air, using eqn. 1.
2. Calculate enthalpy content H_{return} of the return air, using eqn. 1.
3. Calculate enthalpy content H_1 of point 1, mixture of return air and ventilation air, using the ration between ventilation and circulation:

$$H_1 = \frac{flow_{ventilation}}{flow_{circulation} + flow_{ventilation}} * H_{amb} + \frac{flow_{circulation}}{flow_{circulation} + flow_{ventilation}} * H_{return} \quad \text{[kJ/kg]} \quad (2)$$

4. Calculate enthalpy content H_3 of point 3 ($T_{setpoint}$, $RH_{setpoint}$).
5. Read dewpoint temperature of setpoint from Mollier diagram or moist air table and calculate enthalpy content H_2 of point 2 (dewpoint temperature of $T_{setpoint}$).
6. Enthalpy reduction required by refrigeration: $dH_{refrigeration,required} = H_1 - H_2$.
7. Enthalpy increase required by heating: $dH_{heating,required} = H_3 - H_2$.
8. Calculate $P_{refrigeration,required}$ using:

$$P_{required} = dH_{required} * 1.27 * flow_{circulation} / 3600 \quad (3)$$

9. Calculate $P_{heating,required}$ using eqn.3.
10. Check whether $P_{refrigeration} > P_{refrigeration,required}$
    e.g. $P_{refrigeration}$ = 11 kW < $P_{refrigeration,required}$ = 25.2 kW: insufficient capacity
11. Check whether $P_{heating} > P_{heating,required}$

e.g. $P_{heating}$ = 6 kW < $P_{heating,required}$ = 8.1 kW: insufficient capacity

12. If {($P_{refrigeration}$ > $P_{refrigeration,required}$) and ($P_{heating}$ > $P_{heating,required}$)} then the dehumidification capacity suffices.

Example:

$T_{amb} = 27°C$

1. $X_{amb} = 20 g/kg$

   $H_{amb} = 27 + 20 * (2490 + 1840/1000 * 27)/1000 = 77.8 kJ/kg$

$T_{return} = 21°C$

2. $X_{return} = 10 g/kg$

   $H_{return} = 21*1 + 10*(2490 + 1840/1000*21)/1000 = 46.3 kJ/kg$

$flow_{circulation} = 5500 m^3/h$

3. $flow_{ventilation} = 200 m^3/h$

   $$H_1 = \frac{200}{5700} * 77.8 + \frac{5500}{5700} * 46.3 = 47.4 kJ/kg$$

$T_{sp} = 20°C$

$RH_{sp} = 60\%$

4. $X_{sp,RH=100\%} = 14.9 g/kg$

   $X_3 = 0.6 * 14.9 = 8.9 g/kg$

   $H_3 = 20*1 + 8.9*(2490 + 1840/1000*20)/1000 = 42.5 kJ/kg$

5. $T_{sp} = 20°C$

   $X_{sp} = 8.9 g/kg$

   $T_{sp,D} = 12°C$

   $H_2 = 12*1 + 8.9*(2490 + 1840/1000*12)/1000 = 34.4 kJ/kg$

$H_1 = 47.4 kJ/kg$

6. $H_2 = 34.4 kJ/kg$

   $dH_{refrigeration,required} = H_1 - H_2 = 13 kJ/kg$

$H_3 = 42.5 kJ/kg$

7. $H_2 = 34.4 kJ/kg$

   $dH_{heating,required} = H_3 - H_2 = 8.1 kJ/kg$

8. $P_{refrigeration,required} = 13*1.27*5500/3600 = 25.2 kW$
9. $P_{heating,required} = 8.1*1.27*5500/3600 = 15.7 kW$
10. $P_{refrigeration}$ = 11 kW < $P_{refrigeration,required}$ = 25.2 kW: insufficient capacity
11. $P_{heating}$ = 6 kW < $P_{heating,required}$ = 8.1 kW: insufficient capacity

9 Appendix II, water intake and required defrost interval in relation to ventilation.

The water intake W_{intake} by ventilation is given by:

$$W_{intake} = flow_{ventilation} * 1.20 * (X_{amb} - X_{return}) / 1000 \qquad \text{[(kg water)/h]} \qquad (4)$$

with

$flow_{ventilation}$ = ventilation air flow rate [m^3/h], can be set between 0 and 200 m^3/h

X_{amb} = ambient absolute humidity [(g water)/(kg air)], typically up to 20 g/kg

X_{return} = return air absolute humidity [(g water)/(kg air)], typically in range 3 – 7 g/kg.

e.g.

$$W_{intake} = 60\,m^3/h * 1.20\,kg/m^3 * (20\,g/kg - 7\,g/kg)/1000 = 0.94\,kg/h$$

To determine the necessary defrost interval, choose the allowable 'max. ice' accumulation during the trip (typically 'max. ice' should be about 7 kg) and follow Fig. 11.

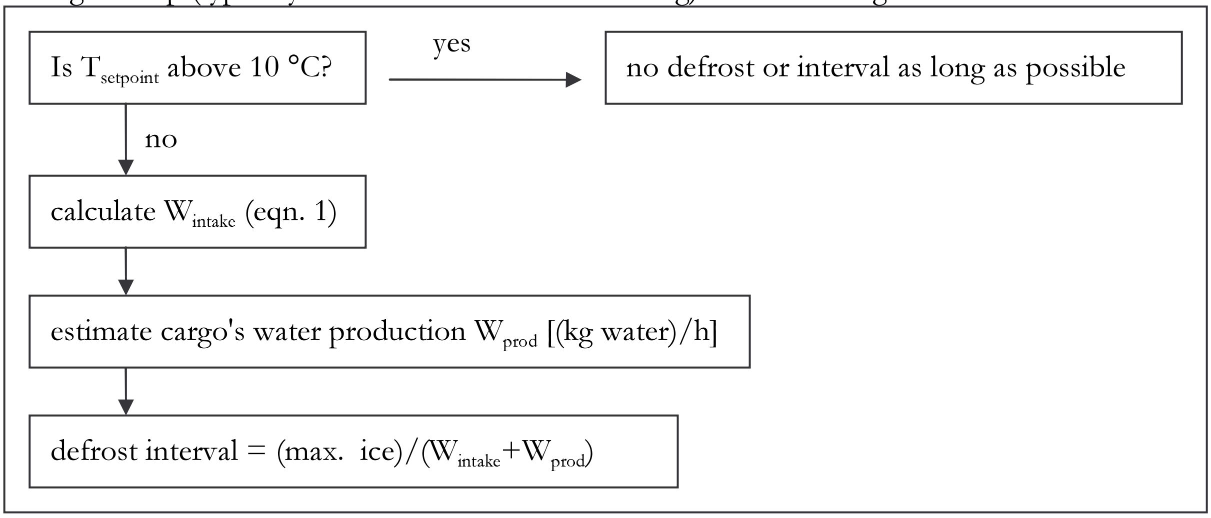


Fig. 11, defrost interval decision tree.

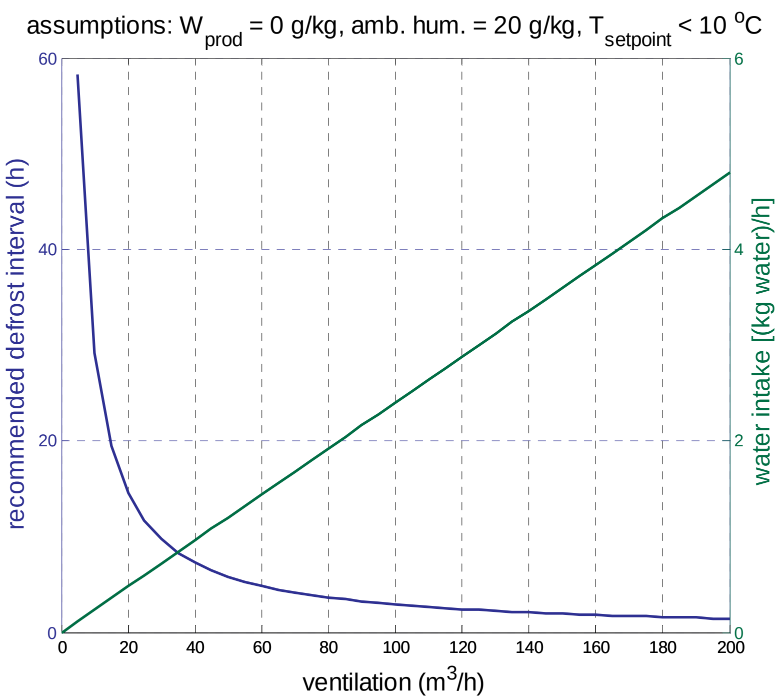
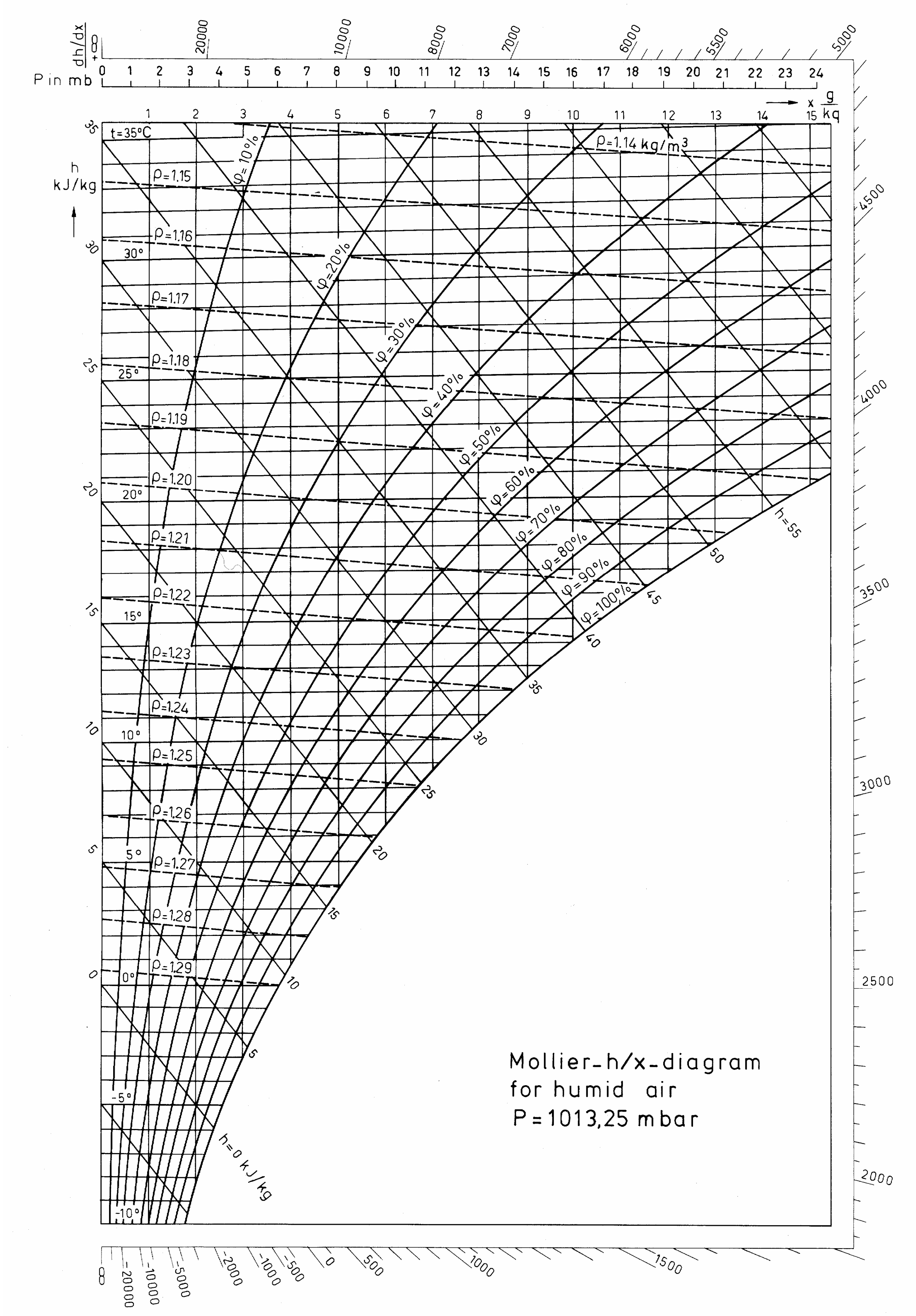


Fig. 12, example of recommended defrost interval as a function of ventilation rate for a specific case.

10 Appendix III: Mollier diagram, cq. h/x diagram for humid air



11 Appendix IV: flowerbulb shipper's checklist

Shipper's (vendor's, exporter's) check list for flowerbulb shipment in reefer containers

reefer container no. (e.g. MWCU 675342[9])	
ATO certified	☐ yes, ☐ no
CONTAINER INSPECTION	
4 drain holes clean and open	☐ yes
visible defects in container inner or outer walls	☐ yes, ☐ no
visible defects at T-bars or bulkhead bottom plate	☐ yes, ☐ no
visible defects of rubber door gasket	☐ yes, ☐ no
container clean internally	☐ yes
container precooling okay	☐ yes, ☐ no, ☐ not applicable
REEFER UNIT SETTINGS	
temperature setpoint	
unit of temperature setting	☐ °C, ☐ °F
fresh air vent setting	m^3/h
defrost interval	☐ off, ☐ auto, hours
relative humidity setpoint	☐ off, %
fan speed	☐ hi(gh), ☐ alt(ernating), ☐ lo(w)
bulb mode	☐ on, ☐ off
defrost termination temp. (N.A. if bulb mode off)	°C, ☐ N.A. (not applicable)
CARGO ISSUES	
cargo stowed below load line	☐ yes
filler/dunnage in center channel or chimneys	☐ yes, ☐ no
cargo stowed beyond T-section floor	☐ no
T-bars occupied entirely	☐ yes
no. of mobile temp. recorders placed	
mobile temp. recorders started	☐ yes
ident. number of door seal applied	
ACCOUNT	
checked by (person's name)	
date	
place	

AGROTECHNOLOGY & FOOD SCIENCES GROUP WAGENINGEN UR

12 Appendix V, interesting internet links

site	description
www.tis-gdv.de	transport information service
www.containerhandbuch.de	container handbook
www.ba.ars.usda.gov/hb66/contents.html	Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks
www.ppecb.com	perishable produce export control board
www.maerskline.com/link/?page=brochure&path=/our_services/cool_facts	refrigerated services: general reefer information from Maersk Line
www.reefertransport.nl	Wageningen UR site for reefer transport

Acknowledgements

We thank Nieberding Verzekeringen (www.nieberding.nl) for supporting us, not only financially, in preparing this reefer units guide for flowerbulb shipment. Moreover we thank Veldboer Agrex, K-Services, Thermo King, Daikin and Carrier for their kind cooperation.

Disclaimer

Wageningen UR, AFSG and the authors do not accept any liability for damages or losses of whatever nature, that may result, directly or indirectly, from the use of the information contained in this document.

