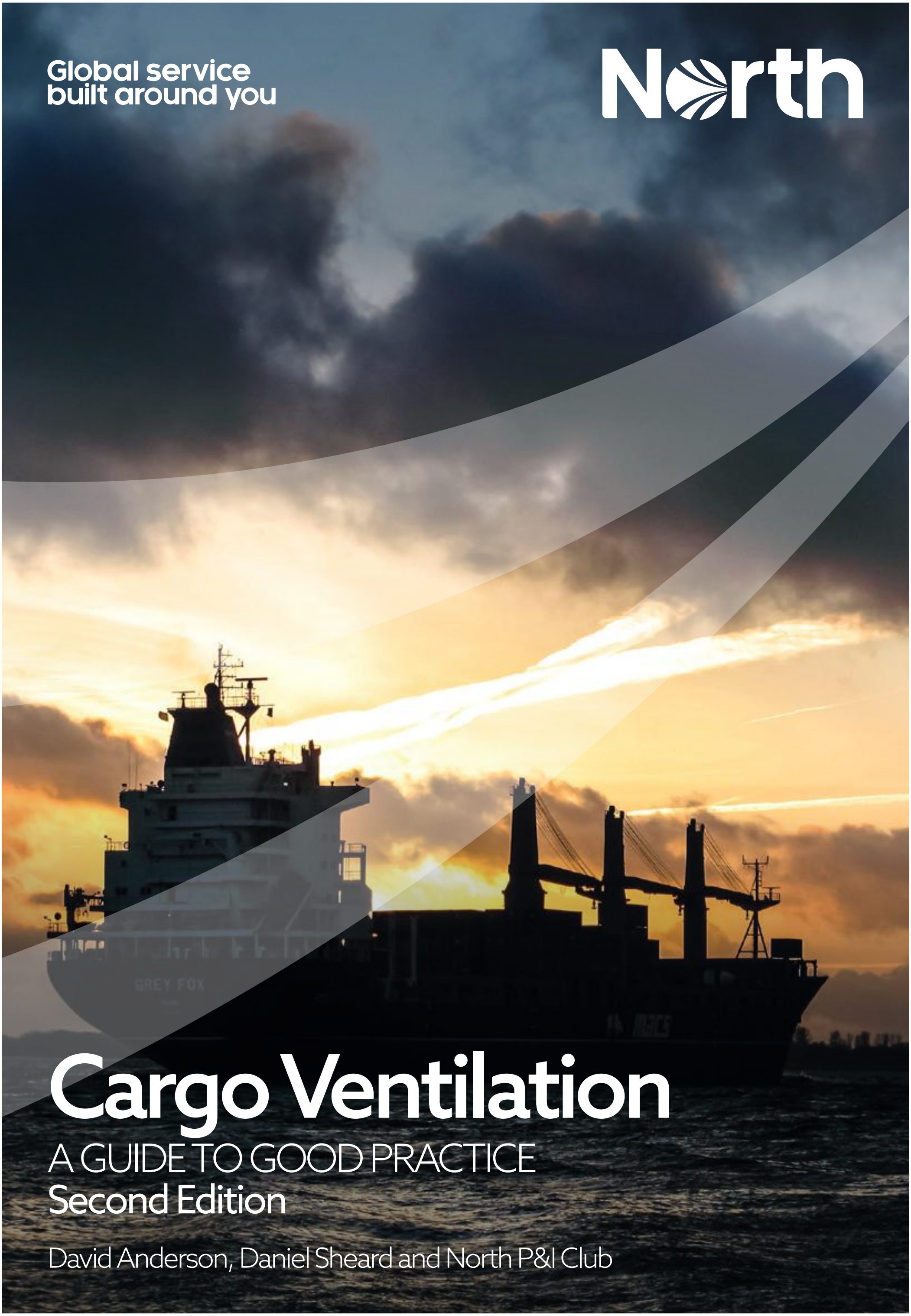

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Cargo Ventilation

A GUIDE TO GOOD PRACTICE
Second Edition

David Anderson, Daniel Sheard and North P&I Club

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TERMS OF USE

Chapter 1

Introduction

Topics covered in this chapter

Why ventilate?

Safety

How to use this guide

Glossary of terms

WHY VENTILATE?

There are numerous reasons for ventilating a ship's holds. Among these are:

- ensure an adequate oxygen level for people to enter the holds
- remove poisonous, flammable gases or fumigant gases
- attempt to prevent condensation or 'sweat' (Fig. 1).

Prevention of sweat is probably the most common reason for ventilating. However, it seems to be the one which causes seafarers and ship operators the most problems, and it is the one on which this guide will concentrate.

Fig. 1. **Ventilation can prevent condensation or 'sweat' forming on hold steelwork and dripping onto cargo**

This guide relates to ships with conventional ventilation systems, both natural and mechanical. It does not apply to refrigerated ships, or to those with holds provided with de-humidifiers.

There are also many misconceptions about what can be achieved with ventilation on board a ship, such as cooling or preventing self-heating of cargoes. These fallacies, and the limited situations in which ventilation can be used to control cargo temperature, are outlined.

Later sections explain why sweat forms, and how it can be controlled by ventilation. But quite simply, if sweat is allowed to form without any effective attempt to check it, cargo wetting and expensive claims can result (Fig. 2). Correct ventilation may not always prevent damage to the cargo but, if correct ventilation has been carried out and properly recorded, it should be easier to defend the resulting claim.

In an ideal world, proper attention to ventilation will ensure that the cargo arrives undamaged at the discharge port. However, this may not always be the case. Even if ventilation is possible, it may be that the cargo cannot be ventilated sufficiently to prevent some sweat forming. It may even be that the inherent moisture content of the cargo is so high that no amount of ventilation will prevent damage.

If extensive sweat damage occurs, it is likely that a claim against the ship will follow. To defend that claim successfully, it will be necessary to demonstrate that the master understood the principles of ventilation and that, based on their understanding, the ship's holds were ventilated during the voyage correctly and as thoroughly as possible under the circumstances.

It may be that weather conditions experienced on a passage prevent ventilation for part, or all, of the voyage. If so, it must still be demonstrated that the crew acted correctly in withholding ventilation and they did so at the correct times. Therefore, whether the holds are being ventilated or ventilation is suspended because of weather conditions, a detailed record should be kept.

SAFETY

Masters have a duty to take proper care of the cargoes their ships are carrying (and so, therefore, do their officers and crew).

If the nature of the cargo and the circumstances of the voyage are such that ventilation may be necessary,

Fig. 2. **Surfaces of cargoes can be heavily wetted if no ventilation is applied, resulting in a claim against the shipowner**

then that duty extends to taking proper care over ventilation. This in turn means ensuring that the cargo is ventilated when it is appropriate to do so, and that ventilation is suspended when it is not.

However, masters have an overriding responsibility for the safety of their crew. This guide repeatedly stresses the importance of safe entry of personnel into holds. People should only be allowed to enter a ship's hold (for example to take temperature readings or check the condition of cargo) when it has been ensured that all procedures for entry into enclosed spaces have been complied with in full.

When either the empty hold or the cargo has been fumigated at the loading port, particular care should be exercised, especially when entering the hold. In the latter instance, it is often the case that the cargo remains under fumigation, with the ventilation system closed, after the ship has sailed. Often masters will be given instructions to start ventilating their holds a few days into the voyage.

By doing so, they will be removing at least some of the fumigant gas from the holds, and this will be exhausted through the ventilators. It is therefore important to ensure that there is no danger to the crew of inhaling dangerous gas concentrations in this exhaust. Take particular care that fumigant gas does not enter the accommodation, deck lockers or access ways as a result of ventilation. If there is any doubt, take readings with the appropriate gas detection equipment. Under the IMO Recommendations on the Safe Use of Pesticides in Ships Applicable to the Fumigation of Cargo Holds, the fumigators should ensure this is available on board, and in good working order. The use of an oxygen meter alone is not enough.

The cargo holds should only be entered when the atmosphere has been tested as safe by authorised personnel. It should also be noted that fumigant gases will normally penetrate to the bottoms of the cargo compartments (some are significantly heavier than air). By contrast, the ventilating air will penetrate neither into the cargo stow itself nor generally to the lower levels of the hold.

Therefore, even if sampling has shown that it is safe to enter the holds above the cargo, potentially fatal concentrations of gas may still be present lower down (for example, in the trunking of an Australian-type hold ladder).

HOW TO USE THIS GUIDE

This guide has four main colour-coded sections:

- quick reference **(red)**
- practical guidance **(orange)**
- practical considerations **(green)**
- scientific background **(blue)**.

The quick-reference section, Chapter 2, provides a summary of the practical guidance and considerations contained in Chapters 3 and 4. Chapter 5 provides the scientific background for the previous chapters together with a worked example of relative humidity and dew point.

GLOSSARY OF TERMS

There are various technical terms used in this guide, of which brief definitions are given below. Where appropriate, more detailed definitions are contained in the text.

Technical terms used in this guide	
Absolute humidity	The actual quantity of moisture contained in the air in absolute terms.
Cargo sweat	Condensation or 'sweat' forming directly on the cargo.
Condensation	Water deposited by relatively warm, moist air when it comes into contact with a relatively cool surface.
Dew point	The temperature at which moisture in the atmosphere will start to condense.
Dew-point rule	Ventilate when the dew point of the outside air is lower than the dew point of the air in the hold.
Dry-bulb temperature	Temperature reading from a normal mercury-in-glass thermometer.
Humidity	Moisture contained in the air.
Hygroscopic cargoes	Cargoes that have a moisture content that can interact with the air.
Mechanical ventilation	A ventilation system which incorporates powered fans.
Mechanical ventilation capacity	The capacity of the fans in a mechanical system is normally expressed in terms of the number of air changes per hour which can be achieved when the hold in question is empty.
Natural ventilation	A ventilation system which does not incorporate fans.
Non-hygroscopic cargoes	Cargoes which either do not have a moisture content, or at least do not have one which can interact with the air.
Outside air	The atmospheric air surrounding the ship.
Relative humidity	The quantity of moisture contained in the air as a percentage of the maximum quantity it can hold at that temperature.
Saturated	Air containing its maximum possible quantity of moisture is said to be 'saturated'.
Ship's sweat	Condensation or 'sweat' forming on the steelwork in a ship's hold.
Sweat	Condensation forming in a ship's hold, either on the cargo or on the ship's steelwork.
Three-degree rule	Ventilate a hygroscopic cargo if the temperature of the outside air is at least 3°C below that of the cargo temperature (taken at loading).
Unstable	A term applied to agricultural products, including grains, which have an inherent moisture content too high for them to be stored and carried in a hold without deterioration. Such cargoes are liable to self-heat, and to become spoiled as a result.
Wet-bulb temperature	Temperature reading from a mercury-in-glass thermometer with wet muslin wrapped around the bulb.

Chapter 2

Quick Reference

Topics covered in this chapter
When to ventilate
Cargoes that may require ventilation

This chapter is a summary of the practical guidance and considerations contained in Chapters 3 and 4 of this guide. All words and expressions in **bold print** are defined in this guide and included in the index.

WHEN TO VENTILATE

This guide will consider two rules that may help a seafarer decide whether to ventilate a ship's hold.

Rules on when to ventilate	
Dew-point rule	Ventilate when the dew point of the outside air is lower than the dew point of the air in the hold.
Three-degree rule	Ventilate a hygroscopic cargo if the temperature of the outside air is at least 3°C below that of the cargo temperature (taken at loading).

If either of these criteria is satisfied, then the hold should be ventilated so long as factors such as heavy spray do not prevent ventilation.

In short, it is likely that ventilation will only be appropriate when a warm cargo is being carried into cooler weather.

If a comparison of **dew points** indicates that ventilation is appropriate, but the temperature of the outside air appears to be too warm in relation to the cargo, check carefully that either the comparison of **dew points** or the **three-degree rule** are giving correct readings, and that the information is realistic.

CARGOES THAT MAY REQUIRE VENTILATION

Below are lists of cargoes that may require ventilation (depending on the above rules) and of those which will not. It must be emphasised that these lists are only intended as a guide and that they are not (and cannot be) comprehensive.

If a master is unsure whether to ventilate a commodity which is to be carried from a hot to a cool climate, then consider whether it is hygroscopic – if it is, then ventilate according to the rules.

Cargo that should be ventilated according to the rules

The following cargoes are **hygroscopic** and should be ventilated according to the rules:

- cocoa beans and their products
- coffee beans and their products
- grains
- anything else of a vegetable nature, such as alfalfa
- newsprint
- oil seeds
- paper and paper products
- rice
- timber and timber products
- raw unrefined sugar
- fibrous cargoes – wool, cotton and jute
- animal feedstuffs – all extraction, expeller meals, pellets, distillers dried grains, wheat middling pellets, bran pellets, fishmeal, citrus pulp pellets, etc. (note that these may generate heat and IMO regulations may take precedence).

Cargo that requires ventilation to remove heat

Examples of cargoes that require ventilation to remove heat are:

- potatoes
- onions.

These are usually carried refrigerated. If they are carried in a ventilated hold, close attention should be paid to proper **stowage**, and to any written carriage instructions.

Cargo that reacts with oxygen to produce heat

Many commodities can react with atmospheric oxygen to produce heat. Examples include:

- direct reduced iron (DRI)
- coal
- coke
- seed cakes (expeller and extraction meals)
- fishmeal.

It is important to note that this is not a complete list.

Carriage of these materials, including when to ventilate, is governed by schedules in the International Maritime Dangerous Goods (IMDG) Code and the International Maritime Solid Bulk Cargoes (IMSBC) Code. Such considerations, as set out in the provisions of these IMO codes (which must always be consulted), are paramount and overrule considerations such as **ship's sweat**.

Non-hygroscopic cargoes subject to sweat damage

The following cargoes are **non-hygroscopic** but may be damaged by contact with **ship's sweat**:

- steel and steel products
- other water-sensitive metals and metallic products.

Dunnage

Dunnage is not, of course, a cargo. However, bamboo and timber **dunnage** are **hygroscopic**, and green timber dunnage can have a high moisture content. Where large quantities are used, the dunnage may itself act as a reservoir of moisture in the same way as a hygroscopic cargo does.

The presence of dunnage should not be overlooked when considering whether **a non-hygroscopic** cargo will require ventilation. If green dunnage is used and the rules dictate that a hygroscopic cargo would be ventilated, then ventilation should be carried out.

Cargoes that should not be ventilated

An example of a cargo that should not be ventilated is:

- bagged refined sugar.

Mixed cargoes

Problems may be encountered when carrying cargoes that have different ventilation requirements in the same hold. Both requirements cannot be met and, in general, there is no way to solve this problem.

Avoid loading cargoes with substantially different temperatures into a single cargo space. Any cargo loaded cold into a cargo space with a warm **hygroscopic** cargo will be at risk of **cargo sweat**, whatever regime of ventilation is applied.

Chapter 3

Practical Guidance

Topics covered in this chapter

What is sweat? The simple explanation

Know your cargo: hygroscopic and non-hygroscopic cargoes

Finding the dew point

Three-degree rule – for hygroscopic agricultural cargoes only

How effective is ventilation?

When should cargo be ventilated?

When should ventilation be stopped?

Types of ventilation system

Importance of record-keeping

WHAT IS SWEAT? THE SIMPLE EXPLANATION

There are two types of sweat: ship's sweat and cargo sweat.

Types of sweat	
Ship's sweat	Sweat forming on the steelwork in a ship's hold (and can therefore drip or run onto the cargo)
Cargo sweat	Sweat forming directly on the cargo

In each case, wetted cargo – and a cargo claim – can result.

Chapter 5 gives a detailed scientific explanation of why and how both types of sweat form. But an in-depth knowledge is not necessary for an understanding of the basic principles involved. A seafarer does not need such detailed knowledge to make the correct decision on whether to ventilate.

A seafarer does, however, need a basic understanding, and that is what this chapter aims to provide – starting with condensation.

Definition of condensation
Water deposited by relatively warm, moist air when it contacts a cool surface

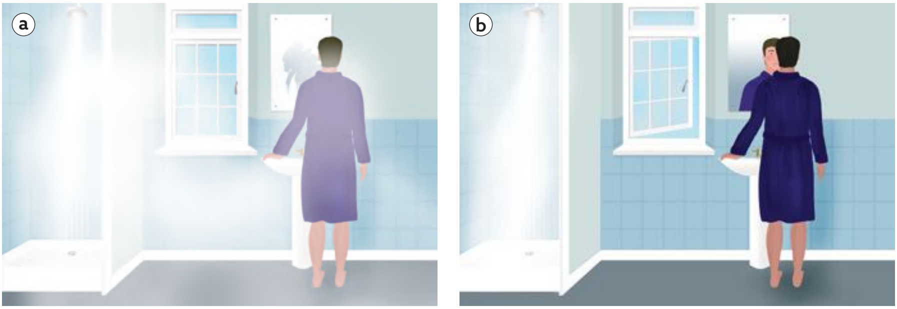

Fig. 3. **Warm moist air condensing on a cold bathroom mirror (a) is a good analogy for what happens in a ship's hold, opening bathroom windows provides ventilation and prevents the mirror from misting over (b)**

An everyday example of condensation occurs when taking a hot shower. We all know that if there is a mirror in the bathroom it is likely to mist over. This is because the bathroom will be full of warm, moist, 'steamy' air from the shower. The mirror is cold, and it attracts condensation (Fig. 3).

When trying to determine if sweat could form under particular circumstances, it might prove useful to think of the bathroom mirror analogy.

At this stage it is necessary to introduce five technical terms which refer to atmospheric moisture. These are considered in detail later in Chapter 5. However, at this stage it will be helpful to give a more detailed definitions than those contained in the glossary in Chapter 1.

Atmospheric moisture terms	
Humidity	No matter how dry it may seem, virtually all air contains some moisture. This atmospheric moisture is called 'humidity'.
Absolute humidity	Any means of actually quantifying the amount of moisture in air gives a measure of absolute humidity in that air. One way would be to give the amount (mass) of moisture per unit volume of air, kg/m^3.
Saturation	The warmer the air is, the more moisture it can contain. At any given temperature there is an upper limit to the amount of water a quantity of air can hold. When it contains this maximum amount, it is said to be 'saturated'.
Relative humidity	When air is not saturated, the ratio of the actual quantity of water it contains to the maximum it can hold is called the 'relative humidity' (RH) and is expressed as a percentage. When air is saturated, its relative humidity is 100%.
Dew point	As stated above, warm air can hold more moisture than cold air. Therefore, if warm air with a relative humidity of, for example, 75% is progressively cooled, although the absolute amount of moisture it contains will remain constant, its relative humidity will steadily increase. As it cools, the maximum amount of moisture it can contain decreases until, if it is cooled sufficiently, it will become saturated and its relative humidity will then have risen to 100%. Any further cooling will lead to condensation. The temperature at which this happens is called the 'dew point'. The concept of dew point is fundamentally important in the formation of sweat.

To help illustrate atmospheric moisture terminology, return to the bathroom mirror. When a hot shower is running, the 'steamy' air in the bathroom is warm and it contains a lot of moisture. Its humidity will be high in absolute terms and, more importantly, it is generally the case that the bathroom air will have a high relative humidity.

The mirror glass is, relatively speaking, much cooler. Warm, moist air coming into contact with it will immediately be cooled below its dew point. Water will condense out, and it will be deposited on the cool surface of the mirror. A similar phenomenon occurs, of course, on any cool surface in the bathroom, but it is particularly noticeable on the mirror.

It is important to understand that, under these circumstances the air does not deposit all of its contained moisture. Rather, as it loses moisture, its relative humidity drops, and condensation should stop as soon as the relative humidity falls below 100%. Of course, for as long as the hot shower is running, moisture in the bathroom air is, in effect, being continually 'topped up' and condensation will continue to form.

Applying the same basic principles to a ship's hold, we can see that if moist air in the hold is cooled below its dew point, condensation will occur.

There are basically two sets of circumstances in which hold condensation may happen. Both these processes will be easier to understand if a general rule regarding the stability of cargo temperature is borne in mind.

Cargo temperature stability general rule

Most cargoes (particularly bulk and bagged cargoes) will only change their temperature slowly, if at all, during a voyage.

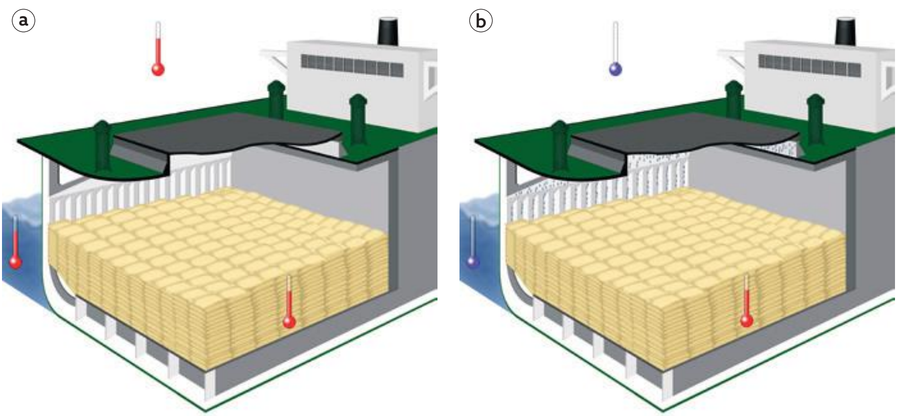

Fig. 4. **Ship's sweat: moisture in unventilated air around a cargo loaded in a warm region (a) will condense onto hold surfaces when the ship arrives in a cooler region (b)**

For example, if bagged cocoa is loaded in West Africa, the bags and their contents will be at ambient temperature. Even after a prolonged voyage into colder weather, the temperature of the cocoa within the stow will remain virtually unchanged.

If the ship has ventilated, then the cargo around the edges of the stow will cool down. But go just a short distance below the surface, the cocoa will remain warm for a considerable time. The same rule applies in reverse: cargo loaded in cold weather will remain relatively cool as the vessel sails into a warmer climate.

Example of ship's sweat

Consider a vessel that loads cargo in a warm climate where the atmospheric humidity is high; West Africa is a good example. If its voyage takes it to an area where the weather is much cooler, then the steelwork of its decks and topsides will cool down. It may very easily cool below the dew point of the air trapped in the hold and sweat will form inside the hold on the upper parts of the ship's structure. The same will happen below water level if the vessel enters an area of low sea temperature (Fig. 4).

Example of cargo sweat

Consider a vessel that loads cargo in a cold climate; northern Europe in winter for example. If it sails to an area which has warm, moist weather then, so long as the holds remain sealed, there will be no problem. However, if the master decides to ventilate the cargo compartments, then it is likely that the outside air will be cooled below its dew point as it enters the holds and, again, sweat will form. This time, it will be deposited directly onto the cargo (Fig. 5).

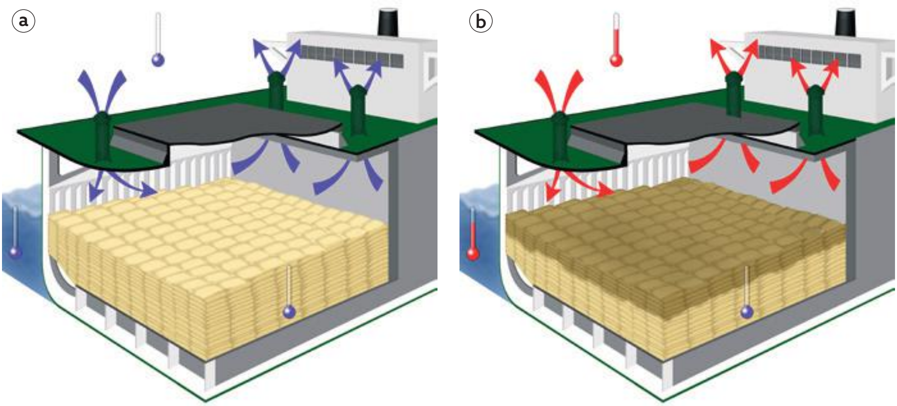

Fig. 5. **Cargo sweat: moisture in ventilated air around a cargo loaded in a cold region (a) will condense onto cargo surface when the ship arrives in a warmer region (b)**

KNOW YOUR CARGO: HYGROSCOPIC AND NON-HYGROSCOPIC

For the purposes of considering ventilation, cargoes can be divided into two general categories – hygroscopic and non-hygroscopic.

Definition of hygroscopic cargoes
Cargoes that have a moisture content that can interact with the air.

In a closed unventilated hold, the moisture and temperature levels of the air will be governed by the cargo.

If condensation is occurring in a hold containing a hygroscopic cargo, the moisture in the air will be 'topped up' with moisture from the cargo so that a continuous process of condensation can occur when outside temperatures are sufficiently low. This is rather like the earlier bathroom mirror example, with the running shower replenishing the moisture in the air and allowing further condensation.

Hygroscopic cargoes include all agricultural crops and commodities, such as grains, oilseeds and animal feedstuffs. Most, but by no means all, hygroscopic cargoes are biologically 'alive'. For instance, sunflower seeds will sprout and grow if planted. Like all living things, these seeds are always respiring, and can therefore produce heat.

If grain and oilseed cargoes are dried prior to shipment and are effectively dormant, the heat produced by respiration on board a ship is so small it can be ignored. There is therefore no need to remove heat from a properly dried grain cargo on board a ship. When grain cargoes are over-moist or become wetted, moulds grow on the grain, often producing large amounts of heat. This is a different matter.

Some fruit and vegetable commodities are shipped in a non-dormant state and these can produce significant amounts of metabolic heat. These commodities are often carried under refrigeration but are sometimes carried using ventilation. This is discussed separately under the heading *Cargoes that generate metabolic heat* in Chapter 4.

Definition of non-hygroscopic cargoes
Cargoes that either do not have a moisture content, or at least do not have one which can interact with the air.

Examples of non-hygroscopic cargoes are steel and machinery. However, a hold containing steel or machinery may also contain substantial quantities of timber dunnage, which is hygroscopic. Indeed, dunnage or pallets can contain substantial amounts of moisture.

FINDING THE DEW POINT

If the decision whether to ventilate is to be based strictly on scientific principles, the master needs the data on which to base that decision. Unfortunately, such data is not always readily available.

Dew point is normally obtained by comparing the readings of a set of wet-bulb and dry-bulb thermometers. Mariners should be familiar with these, since a set is normally hung on the bridge wing, often in a slatted wooden box known as a Stevenson screen (Fig. 6).

The dry-bulb thermometer is an ordinary mercury-in-glass thermometer. The wet-bulb thermometer has a muslin wick around its bulb, and the end of the wick is submerged in a small reservoir of pure water below the thermometer.

The water soaks into the wick, so that the bulb of the thermometer is surrounded by wet muslin. As the wind blows across the thermometer, some of the water evaporates and this cools the thermometer. The drier the air blowing across the thermometer the faster the water will evaporate, the more the thermometer will be cooled, and the greater will be the difference between the wet-bulb and dry-bulb readings. From this difference the dew point can be read from tables.

However, there are practical problems associated with using wet-bulb and dry-bulb thermometers.

Measuring the outside air

Measuring the outside air should not cause too much of a problem as it is normal for a set of wet-bulb and dry-bulb thermometers to be present on the bridge wing. But it is important that

- the thermometers be hung on the windward side of the bridge (so that there is a good flow of air over the wet bulb)
- they are in the shade
- they are not affected by extractor vents (such as from the galley)
- the water reservoir is kept topped up
- pure water (or distilled water) is used.

So long as those precautions are taken, the dew point of the outside air can be determined with reasonable accuracy.

Fig. 6. **Stevenson screen, normally located on a ship's bridge wing, contains wet-bulb and dry-bulb thermometers and is used to measure the dew point of the outside air**

Measuring the air in cargo holds

Unfortunately, measuring the dew point in the holds is not as straightforward. The problem comes in getting a sufficient flow of air over the wet bulb for evaporation to take place. Unless there is a good flow of air, there will be insufficient evaporation (or, indeed, none at all), and the temperature reading from the wet-bulb thermometer will be artificially high.

Clearly, it is of little use simply lowering into the hold a set of wet-bulb and dry-bulb thermometers similar to those used on the bridge. If the hold ventilation has been shut off there will be no airflow in the hold, and therefore no flow of air across the wet bulb. Opening the ventilation may create a reasonable air flow if the thermometers are positioned in the air stream, but the wet-bulb thermometer will then be measuring the air coming in through the ventilators rather than the residual atmosphere in the hold itself.

Fig. 7. **Aspirated or 'whirling' psychrometer also contains wet-bulb and dry-bulb thermometers and is used to measure the dew point of the air in the hold**

One way to get around the problem is by using a device known as an aspirated or whirling psychrometer (Fig. 7). This device is described in detail in Chapter 4. Briefly, it comprises a set of wet-bulb and dry-bulb thermometers in a frame, which can be manually whirled around to create the airflow.

But there are two problems with the aspirated psychrometer.

- If the user is impatient, they may stop whirling the psychrometer before the wet bulb has properly cooled. Once again, the reading will be artificially high. If a falsely high wet-bulb reading is taken, the dew point of the air in the hold will appear to be higher than it actually is. Since it would be normal to ventilate if the dew point of the outside air is lower than that in the hold, if the crew believes the dew point in the hold is higher than it actually is, they may ventilate when they should not do so.
- It requires the user to enter the hold. This may be impossible, particularly if the hold is completely full. Even when it is physically possible, it may very well be unsafe (Fig. 8). **A closed hold should never be entered until proper entry into enclosed space procedures have been carried out.**

Fig. 8. **Full precautions for entry into enclosed spaces need to be followed before entering a cargo hold to measure the dew point of the air**

There is a further difficulty that cannot be overcome when measuring the dew point in holds to determine whether to ventilate. If the ambient conditions are such that ventilation is appropriate, then presumably the ship will have been applying ventilation. As already stated, for an in-hold dew point measurement to be meaningful, it must be measuring the dew point of the hold atmosphere and not that of the external ventilating air.

Therefore, ventilation would need to be suspended for some time prior to taking a reading. But for how long? And in the meantime, what happens if condensation forms? However desirable it may be to compare dew points before deciding whether to ventilate, in all too many cases it may simply be impossible to do so accurately or indeed at all.

Fortunately, this does not mean that the master is forced to rely upon guesswork. There is an alternative method which is reliable for virtually all hygroscopic cargoes and does not require data that is almost impossible to measure.

THE THREE-DEGREE RULE – FOR HYGROSCOPIC AGRICULTURAL CARGOES ONLY

For most cargoes, and particularly those which effectively fill the hold, the cargo temperature everywhere except at the periphery of the stow will change little, if at all, during the voyage.

If the temperature is measured at the time of loading, the master can be reasonably confident later in the voyage that the bulk of the cargo will still retain that temperature. By contrast, the temperature of the outside air will change, both between day and night and, in the longer term, over the course of the voyage.

However, it is not difficult to measure the temperature of the outside air. It can be done simply by reading the dry-bulb thermometer on the bridge, although ideally the temperature should be measured close to the inlet ventilators.

Where hygroscopic cargoes are concerned a very simple rule can then be applied.

Three-degree rule
If the temperature of the outside air is at least 3°C **below** that of the cargo temperature (taken at loading), the master may safely ventilate the cargo as long as factors such as heavy spray do not otherwise prevent ventilation.

The three-degree method has obvious advantages:

- it is easy to apply
- the only measurements required are of the temperature of the cargo at the time of loading and of the outside air whenever ventilation is being considered

– these are straightforward and are less likely to lead to error than determining the dew point

- it does not require anyone to enter the holds during the voyage.

Fig. 9 shows the rule in practice.

HOW EFFECTIVE IS VENTILATION?

It is all very well to state that, according to readings of either dew point or temperature, a cargo should be ventilated to stop sweat forming. But how effective will ventilation prove? Will it prevent the formation of sweat, and therefore protect the cargo from damage? The answers depend on two things. One is the nature of the ventilation system fitted to the vessel and the other is the nature and stowage of the cargo.

It is obvious that a vessel with a powerful mechanical ventilation system should be able to ventilate more effectively that one which has only natural ventilation. It may not be so obvious that, however powerful the ventilation system, there are many cargoes which simply cannot be effectively ventilated.

The basic factor to keep in mind is that the most any shipboard ventilation system can hope to achieve is to replace the air within a hold with air introduced from outside. Essentially, introducing the air at one end, moving it through the air space within the hold, and exhausting it at the other end. If there is cargo in the hold (as there normally will be when ventilation is carried out), the air will at best

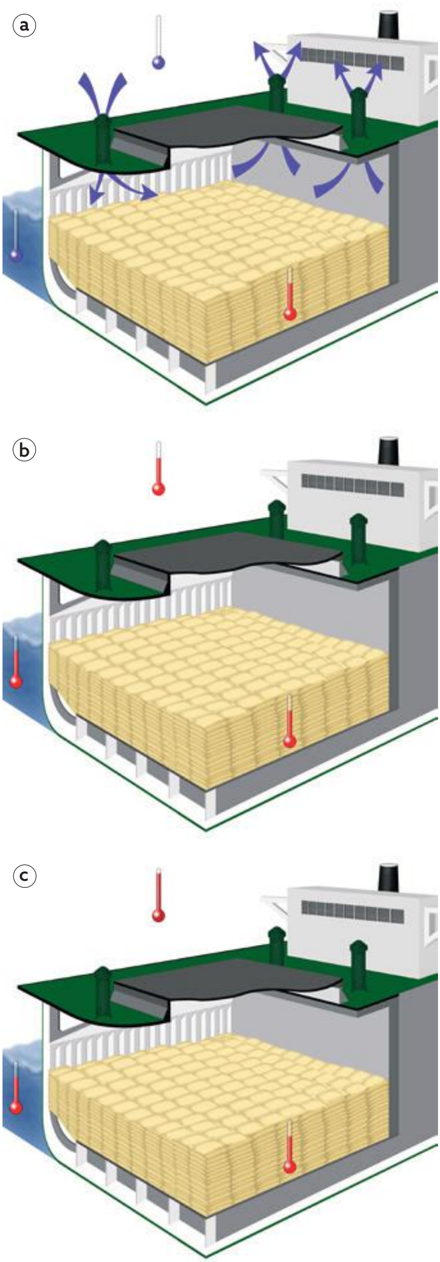

Fig. 9. **Three-degree rule: ventilate when outside air is at least 3°C cooler than the cargo temperature taken at loading (a) but do not ventilate when outside air is at a similar temperature (b) or warmer (c)**

circulate over or around the cargo. The ventilation system cannot be expected to force the air through the cargo itself (Fig. 10).

Bulk cargoes

The only ventilation that can be achieved with a bulk cargo is to circulate air over its surface.

Consider a panamax bulk carrier with 10,000 t of bulk cargo in each hold. Air may be circulated over the top of the stow in each hold and, depending upon the nature of the cargo, it may penetrate a few centimetres below the surface. But that is all it will do – about 99% of the cargo will be unaffected by the ventilating air.

With a cargo such as grain, which may be stowed up into the coaming space of each hatch, the ventilation will reach even less of the cargo, since air from ventilators mounted between the hatches will not be able to penetrate into the coaming spaces (Fig. 11).

The physical limitations do not necessarily mean that a master should not ventilate a bulk cargo. If, based upon dew point or temperature, the indications are such that they would normally ventilate if they were carrying a bagged cargo in a slack hold, then they should also ventilate a hold fully-laden with a bulk cargo.

The reason is simple. While ventilation may have little effect on a bulk cargo, so long as the indications are correct it will not harm it in any way. If, at outturn, there is a moisture-related problem with the cargo, the master will be able to demonstrate that they ventilated when they should have done.

If the pre-shipment moisture content of certain common bulk cargoes (such as grains and animal feeds) is excessive, then those cargoes will be unstable and liable to heating and consequent deterioration during the voyage. When mould damage is discovered during the discharge of an unstable cargo of this type, it is

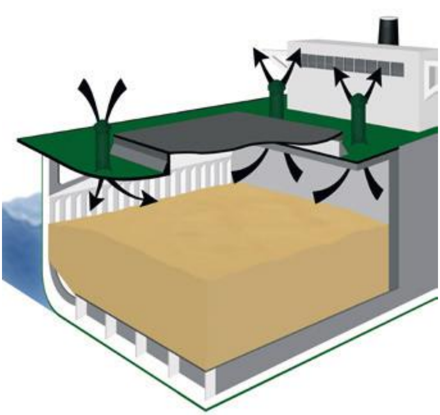

Fig. 10. **Ventilating air only ever moves over a bulk cargo and not through it – 99% of the cargo remains unaffected by ventilation**

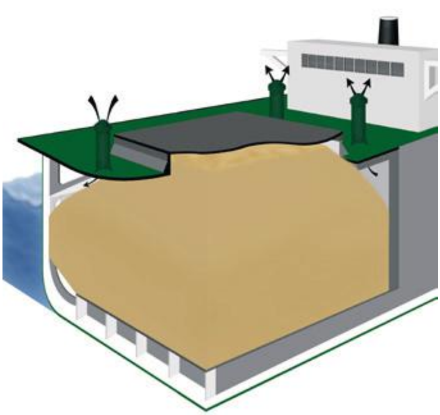

Fig. 11. **Very little ventilation can be achieved in a full hold – but it may be better to do it rather than risk a condensation-damage claim**

not uncommon for cargo receivers to blame the carrying vessel, alleging that it did not ventilate the cargo properly. This is misguided.

However powerful the ventilation fans (assuming it even has mechanical ventilation), no vessel will have been able to do anything to prevent such damage to an unstable cargo. Nevertheless, any potential claim becomes easier to defend if the master can demonstrate that they ventilated, to the capacity of the vessel's system, whenever it was appropriate to do so.

Bagged cargoes

It is not only bulk cargoes that can prove difficult to ventilate effectively. It is tempting to believe that with the ventilation fans working at full power, air will pass not just over the top of a bagged cargo but, so long as an air gap has been left during loading, around its sides and ends as well.

But in practice air will follow the easiest route from the inlet to the extraction ventilator. If both the inlet and extraction openings are close under the deckhead, then the air will tend to flow directly from the one to the other. There is no reason why it should circulate downwards around the stow and between the sides of the stow and the shell plating.

Where bagged cargoes are concerned, the effectiveness of ventilation will clearly improve the more sophisticated the ventilation system is. At the most basic level, a single natural ventilator at each end of a hold, with the inlet just below the deckhead, will have only a very limited effect. The addition of a mechanical fan to one of these will clearly help. The addition of further ventilation openings at a low level will lead to better circulation, particularly if these low-level openings have separate trunkings and perhaps even their own fans.

Likewise, just as mechanical ventilation should be more effective than natural ventilation, a vessel that can achieve, say, 25 air changes per hour on an empty-hold basis should ventilate more effectively than one which can only achieve 10 changes.

Once again, it is important that the master ventilates whenever it is appropriate to do so and keeps detailed records of ventilation. They should include reasons for ventilating or withholding ventilation. This strengthens the shipowner's position in defending claims for cargo damage allegedly caused by improper, or inadequate, ventilation.

WHEN SHOULD THE CARGO BE VENTILATED?

When should a cargo be ventilated? The very basic answer is: when either comparison of dew points, or the three-degree rule, indicates that it should. However, that may not always be the case, and the master may have to take other considerations into account.

Fumigated cargo

It is not uncommon for agricultural cargoes (such as grain, rice, animal feeds, etc.) to be fumigated on board the ship on completion of loading. The master will be given written instructions, either from the charterer or from the fumigator, to keep the vessel's holds sealed for a stated period (while the fumigant does its work), and then to ventilate to remove the residual fumigant gas. The master should follow these instructions.

In cases where the cargo has been fumigated, on no account should anyone enter the holds until these have been certified gas-free at the discharging port. The IMO Recommendations on the Safe Use of Pesticides in Ships Applicable to the Fumigation of Cargo Holds states that authorised personnel at the discharging port should monitor the hold atmosphere before it is entered.

Charterer's instructions

The master may receive instructions from the charterer regarding ventilation. There are some charterers who require the master to submit daily wet-bulb and dry-bulb temperatures of both the outside air and from within the holds to the German weather service (Deutsche Wetterdienst). The weather service then analyses the data and instructs the master on whether to ventilate.

Once again, if the master has been given written instructions from the charterer, these should be followed. But if the master receives advice from the weather service which seems to be inappropriate or reliable in-hold readings cannot be taken, then problems may arise. The most sensible advice in such an event is to contact the charterer, discuss the problem, and obtain confirmation of the charterer's instruction in writing.

A charterparty may also incorporate general instructions on ventilation, sometimes to the effect of 'ventilate the cargo whenever possible'. These should not be seen as a blanket instruction to ventilate regardless. Ventilate only whenever the temperature or dew-point data indicate that it is appropriate.

Where no written instructions are given, the master should either obtain comparative dew points or apply the three-degree rule, as appropriate, and act accordingly based on the results.

Hazardous cargoes

Hazardous commodities are carried according to the schedules in the IMDG Code or IMSBC Code. Some of these schedules incorporate instructions on routine ventilation to be applied, and others list emergency action to be taken in certain circumstances.

In all cases the schedules in the codes should take precedence over ship's sweat considerations.

WHEN SHOULD VENTILATION BE STOPPED?

Of course, it is not enough to only know when to start ventilating. The officer of the watch should remain aware of any change in atmospheric conditions which may require ventilation to be suspended. This does not simply mean paying attention to heavy weather. If the dew point of the outside air rises, it may become necessary to cease ventilation.

TYPES OF VENTILATION SYSTEM

There are two basic types of ventilation system: natural and mechanical (fan-assisted).

It is possible for a system to combine both natural and mechanical ventilation but, for those vessels fitted with a ventilation system, it is normal for it to be of one type or the other.

The object of any ventilation is to provide circulation of air in the holds. For air to circulate there must be both inlet and outlet ventilators. These will commonly be sited at opposite ends of each hold. For obvious reasons, it is important that the extraction ventilators for one hold should not be immediately next to the inlets for the adjacent hold.

Natural ventilation

As its name implies, natural ventilation relies solely on the strength of the relative wind, with no mechanical assistance.

Normally, natural ventilation systems are basic. They are likely to consist at most of a pair of ventilators at each end of the hold (Fig. 12). Some vessels may be fitted only with a single, centreline, ventilator at each end. There may be small ventilators on the hatch covers, either in addition or as an alternative.

The effects of natural ventilation are limited. Only in strong relative winds will there be much airflow, and then sea spray may prevent ventilation. If the relative wind is zero, then no air will enter the ventilators and they will have no effect at all. This may be the case with a following wind, or if the ship is anchored in calm weather.

Fig. 12. **Ventilation systems often incorporate a pair of ventilators at each end of the hold. Natural ventilators rely solely on the wind for airflow whereas mechanical ventilators incorporate fans**

Mechanical ventilation

Mechanical ventilation systems are those which incorporate mechanical fans. Systems which also attempt to condition the hold air, for example by de-humidifying it, are not discussed in this guide.

Mechanical ventilation systems can frequently be as basic as the simplest natural ventilation systems, with their only refinement being the addition of fans. However, more sophisticated systems exist that channel air to different parts of the hold. For example, in a tween-decker it would be common to find separate air delivery into tween-decks and lower holds, and sometimes separate inlets at deckhead and deck level (Fig. 13).

Mechanical ventilation systems are usually rated by their capacity.

Mechanical ventilation capacity
The capacity of the fans is normally expressed in terms of the number of air changes per hour which can be achieved when the hold is empty

The mechanical ventilation capacity is convenient for comparative purposes. Fans that achieve ten air changes per hour, for example, are clearly more powerful than those which achieve only five. However, it is something of a misnomer – if the ship's fans have a capacity of ten changes per hour, then this does not mean that every hour all of the air in the holds will be exchanged ten times.

So, what does a capacity of ten air changes per hour actually mean? It means that if a hold has a volume of, for example, 5,000 m^3, the ventilation fans serving that hold can, between them, deliver 50,000 m^3 of air per hour. It does not follow that all of the air in that hold will be exchanged, either ten times or indeed at all.

Fig. 13. **Ventilation systems can have separate ducting to tween-decks and lower holds**

Design and positioning of ventilators

It is beyond the scope of this guide to describe all designs of ventilator which may be found on a vessel. There are simply too many of them. However, a few general points may be made.

Ventilators may be fitted directly on the hatch covers (Fig. 14). There are also ships which have ventilators mounted on the sides of the hatch coamings. Both locations are generally restricted to natural ventilation systems.

At the other extreme, the ventilation inlets and outlets may be fitted at the tops of the masts (Fig. 15). A fairly common location is on ventilator columns, mounted either on the weather deck or on the top of a mast house (Fig. 16). These may be associated with mechanical systems, with the fans mounted either in the columns themselves or in the mast houses.

Fig. 14. **Ventilators can be mounted on the side of hatch covers as well as on hatch coamings**

Fig. 15. **Ventilator inlets can be positioned on top of king posts or masts**

Clearly, the lower down the ventilation inlets and outlets are mounted, the more likely it is that the ventilation system will have to be closed if the vessel starts shipping spray.

IMPORTANCE OF RECORD KEEPING

For many cargoes, the provision of ventilation has only limited beneficial effect. However, the importance of having a completed ventilation log cannot be overstated. This document will be the vessel's main defence if allegations of improper ventilation are levelled.

There are spreadsheets available which enable day-by-day records to be kept by the vessel of the climatic conditions and the decisions taken. The records should make it clear which rule is being followed – the three-degree rule or the dew-point rule.

Three-degree rule logs

If the three-degree rule is being followed, the log should note the cargo temperature at loading and the records of ambient air temperature.

Each time a decision is made to ventilate or not, that decision – and the reasons behind it – should be evident from the log. On any occasions when ventilation is indicated but is withheld because of weather conditions, that should be noted, including what those conditions were.

Fig. 16. **Mechanical ventilation systems often have ventilators on mast houses which contain the fans**

Ventilation Log

Ship:	Voyage Number:	Port From:	Date Sailed:	Port To:	Date Arrival:	Length of voyage (days):
Amber Nectar	007 JB	Santos	12 April 2016	Dalian	23 May 2016	42

Cargo type: Soya Beans

Mechanical or natural ventilation: Natural

Cargo temperature on loading - this temperature will not change during the voyage

Date	Time	Temperature Outside Air°C	Hold #1 30 °C		Hold #2 30 °C		Hold #3 31 °C		Hold #4 30 °C		Hold #5 32 °C		Hold #6 29 °C		Hold #7 30 °C		Notes
			Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	Temperature Difference	Ventilator Position	
12-Apr-19	0400h	25 °C	-5	C	-5	C	-6	C	-5	C	-7	C	-4	C	-5	C	Fumigation
	0800h	27 °C	-3	C	-3	C	-4	C	-3	C	-5	C	-2	C	-3	C	Fumigation
	1200h	28 °C	-2	C	-2	C	-3	C	-2	C	-4	C	-1	C	-2	C	Fumigation
	1600h	29 °C	-1	C	-1	C	-2	C	-1	C	-3	C	0	C	-1	C	Fumigation
	2000h	27 °C	-3	C	-3	C	-4	C	-3	C	-5	C	-2	C	-3	C	Fumigation
	2400h	25 °C	-5	C	-5	C	-6	C	-5	C	-7	C	-4	C	-5	C	Fumigation
13-Apr-19	0400h	24 °C	-6	C	-6	C	-7	C	-6	C	-8	C	-5	C	-6	C	Fumigation
	0800h	25 °C	-5	O	-5	O	-6	O	-5	O	-7	O	-4	O	-5	O	Start 0900h
	1200h	26 °C	-4	O	-4	O	-5	O	-4	O	-6	O	-3	O	-4	O	
	1600h	26 °C	-4	O	-4	O	-5	O	-4	O	-6	O	-3	O	-4	O	
	2000h	24 °C	-6	O	-6	O	-7	O	-6	O	-8	O	-5	O	-6	O	
	2400h	23 °C	-7	O	-7	O	-8	O	-7	O	-9	O	-6	O	-7	O	
14-Apr-19	0400h	23 °C	-7	C	-7	C	-8	C	-7	C	-9	C	-6	C	-7	C	Stop 0530h heavy rain
	0800h	24 °C	-6	C	-6	C	-7	C	-6	C	-8	C	-5	C	-6	C	Start 1145h
	1200h	25 °C	-5	O	-5	O	-6	O	-5	O	-7	O	-4	O	-5	O	
	1600h	24 °C	-6	O	-6	O	-7	O	-6	O	-8	O	-5	O	-6	O	
	2000h	24 °C	-6	O	-6	O	-7	O	-6	O	-8	O	-5	O	-6	O	
	2400h	23 °C	-7	O	-7	O	-8	O	-7	O	-9	O	-6	O	-7	O	

Fig. 17. **Example of ventilation record log using three-degree rule**

The log should clearly record when the ventilators are opened and when they are closed (Fig. 17). Because the three-degree rule does not involve measurements being taken from the holds, experts suggest that ambient temperature readings are noted every watch in the ventilation log.

As ambient temperatures can change substantially during a day, the need to provide or withhold ventilation can be reassessed as required.

Dew-point rule logs

If the dew-point rule is being followed, recordings of in-hold dew point and ambient dew point need to be kept.

The records should also make it clear where and how the measurements were taken. Again, when ventilation is indicated but is withheld because of weather conditions, that should be noted including what those conditions were. It would be good practice also to record a measure of the loaded cargo temperature.

If conditions change during the course of a day, and that leads to ventilation being started or stopped, that should also be recorded. The log should also indicate whether ventilation was carried out at night time, and if not, why not.

The log should also record whether the vessel has natural or mechanical ventilation. If mechanical, each day's entry should state whether the fans were used or not. A brief note of the locations of the ventilators themselves should be made in the log.

Chapter 4

Practical Considerations

Topics covered in this chapter

Topics covered in this chapter
Stowage
Dunnage
Cargoes that do not fit the rules
Equipment for measuring the dew point
Myth or truth?

STOWAGE

When a cargo is loaded, consider whether that cargo may require ventilation during the forthcoming voyage. If so, then the stowage should be planned to enable ventilation wherever possible.

The crew should first ask themselves what ventilation should achieve. Within the context of this guide, the answer is to control the dew point of the air surrounding the cargo in each hold with a view to preventing (or at the least minimising) the formation of ship's sweat.

That may seem obvious, but it is not always appreciated. The point to note is that, so long as the cargo is stable, there is normally no requirement to ventilate the cargo itself, in the sense of introducing air into the heart of the stow.

If the cargo is not stable, then there will in any event be little or nothing the ship can achieve. But as described later, under *Cargoes that generate metabolic heat*, there are certain exceptions to this general rule.

Ventilation channels

There is little evidence to demonstrate the effectiveness of ventilation channels, despite often requested by charterers when carrying bagged cargoes. There is no reason why the ventilating air should be expected to divert its path through them.

In fact, the argument goes rather beyond that. When ventilation channels are constructed in, for example, a cargo of bagged rice, it is common for there to be at least one fore-and-aft channel with one or more channels running athwartships. Often there are two fore-and-aft channels, aligned with the ventilation grilles. Such channels are either a waste of time or, to the extent that they achieve anything, they will lead some of the air into the heart of the stowage of bags. But so long as the cargo is stable (and a master can only assume that the cargo is indeed stable), ventilation within the stowage is not needed. The requirement is for ventilation of the surrounding air space. At worst, ventilation channels may divert ventilating air from where it is needed.

Except in the case of the exceptions mentioned below, the construction of channels in the stows as an aid to ventilation is to be discouraged. If shippers or charterers insist on their provision for ventilation purposes, then it would be prudent for the master to request written instructions to this effect.

Ventilation of stow periphery

Although nothing can be done to promote the circulation of air around the edge of the cargo, wherever possible care should be taken to stow the cargo to allow space for circulation, rather than blocking it off.

It should be remembered that, unless there are separate ventilation inlets in the hatch coamings (or it is envisaged that the covers will be opened on passage), stowing cargo tightly in the coaming spaces will prevent surface ventilation.

With anything but the most sophisticated ventilation system, there will be little or no penetration of ventilating air to the areas adjacent to the shell plating, particularly at lower levels. It must therefore be foreseen that, in circumstances where ventilation is required, ship's sweat is likely to form in these areas. On a voyage from, say, West Africa to Northern Europe in the depths of winter, where the ambient temperature change is large, the quantity of sweat that may be expected can be substantial.

Once it is appreciated that the ship may be unable to prevent the formation of ship's sweat, then it becomes important to try to protect the cargo from damage by the sweat. At its most basic, that means ensuring the cargo does not come into direct contact with the steelwork.

DUNNAGE

It may be possible to stow the cargo in such a way that a space is left between cargo and steel. However, with a bagged cargo for example, the motion of the ship during the voyage is likely to lead to individual bags collapsing into the spaces between the frames. In any event, it is obviously impossible to leave a space between the bottom-tier bags and the tank top. This is where the correct use of dunnage becomes important, and it is vital to plan the dunnaging before loading starts.

Flatboard dunnage

Traditionally, bagged produce cargoes such as cocoa and rice were protected using flatboard dunnage. On ships specifically intended for such trades, planks known as spar-ceiling were fitted into brackets at the ship's sides, and these would remain permanently in place (Fig. 18). Where there was no spar-ceiling, individual dunnage planks would be positioned against framing, to keep the bags clear of the steelwork. It was common also to position dunnage planks around the insides of the weather-deck hatch coamings.

It was customary to place two layers of boards on the tank tops, to raise the bags clear, and sufficiently closely-spaced to prevent them sagging between the dunnage planks. The two layers would be at right-angles to each other, with the bottom layer aligned to allow water to drain to the bilges.

Although there are still some general cargo vessels with permanent spar-ceiling, it is now uncommon, and of course it is not found in bulk carriers. Furthermore, flatboard dunnage is also less common now. It is expensive, and for quarantine reasons may be difficult to dispose of after the cargo has been discharged.

Alternatives are now commonly used. Rice from the Far East is frequently dunnaged with bamboo poles, although flatboard dunnage is still sometimes used in China.

Bamboo dunnage

The crew can only use the type of dunnage that is available to them. Often, that will mean the type provided by charterers. But it is important to recognise that a bamboo pole is not as effective as a traditional dunnage plank. It is neither as efficient at keeping the cargo away from the steelwork nor, owing to its circular cross-section, is it as stable as a flat plank.

Where the use of materials such as bamboo is unavoidable, take care to ensure they are used in copious quantities and arranged to protect the cargo as best possible. Even then, such arrangements may prove inadequate, particularly on the tank top.

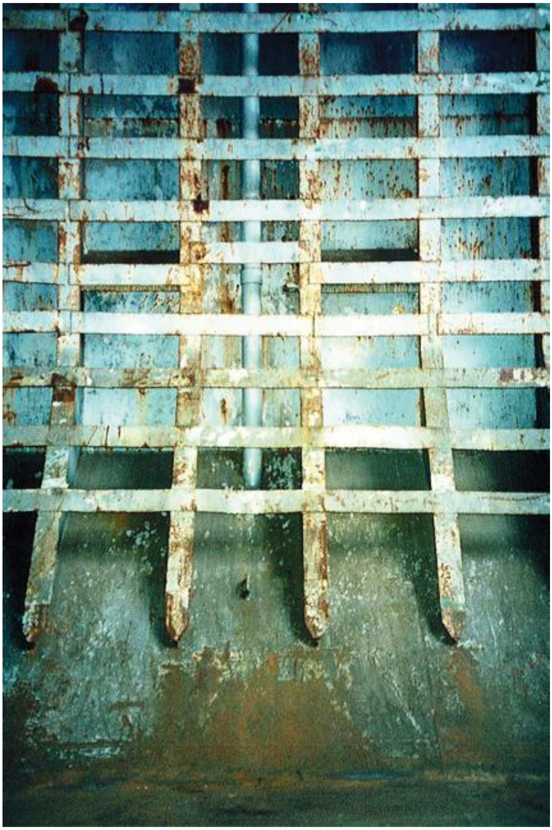

Fig. 18. **Spar-ceiling can be permanently fitted in holds of ships that regularly carry bagged cargoes, helping to prevent cargo touching the sides of the hold**

It is also common to use either bamboo matting ('dunnage mats') (Fig. 19) or Kraft paper – and occasionally both. Used as one component of an effective dunnage system, with planks or poles for example, these can play their part. But as a means to protect cargo from wetting by ship's sweat, they have no practical value. Indeed, by soaking up water and then retaining it, these materials may worsen the problem.

The use of Kraft paper or mats as the main component of a dunnage system may well save money but it will not protect the cargo from damage by sweat.

Another common method of dunnaging for bagged rice cargoes from Asia uses expanded polystyrene foam alongside plastic sheeting (Fig. 20). In this method, thin sheets of the foam are secured directly to the ship's hull between the frames and hatch coaming. Plastic sheets are then used everywhere else.

Rather than keeping the cargo from coming into contact with condensation, the method is intended to prevent condensation by insulating the ship's sides. The effectiveness of the method as a thermal barrier for any temperature differential between the hold and the outside air is unfortunately limited. Thus, it does not prevent all ship's sweat.

Careful application is important. If the application of the materials around the hold is inconsistent and the holds' frames remains exposed, the cargo could sit in

Fig. 19. **Bamboo dunnage mats are often used with bagged rice cargoes. But unless they are kept clear of frames by dunnage planks or poles, they provide little protection against condensation**

contact with the ship's steel in these areas. Consideration during loading should also be given to what will happen to any condensation which does form. If it can run down the plastic sheeting and then contact cargo towards the bottom of a hold, cargo damage is a possibility.

CARGOES WHICH DO NOT FIT THE RULES

It is always difficult to give guidelines to fit all cases. Although many commodities fit into the framework so far discussed, there are a small number which appear at first to fit but in fact do not.

Cargoes that generate metabolic heat

Cargoes such as bagged potatoes, when carried on ships with mechanical ventilation, rather than refrigerated, generate substantial metabolic heat.

There is a distinction to be drawn between cereal cargoes, which are 'alive' and are metabolising (but at a very low rate), and potatoes which generate sufficient metabolic heat that, if they are left stacked in a pile, they will start to self-heat significantly.

The carriage of bagged potatoes as a ventilated cargo is a different use of a ship's ventilation system from, say, the carriage of cocoa in bags. For the potato cargo

Fig. 20. **Dunnage of foam-polystyrene sheets overlain by plastic sheeting (photo courtesy of Allied Maritime Inc.)**

it is essential that the metabolic heat is removed, and for that purpose ventilation channels are used to split the stow into much smaller blocks. Convection within these blocks allows metabolic heat to be lost to the ventilating air.

Refined sugar in bags

Bagged refined sugar is a good example of a commodity that should be hygroscopic but is packaged in such a way that it is not.

If it were placed within normal polypropylene woven bags – such as those used for rice – refined sugar would be highly hygroscopic and therefore difficult to carry successfully. However, in practice, refined sugar is carried in bags with an inner film liner which greatly reduces the interaction between the sugar and the air in its environment. As such, bagged refined sugar behaves largely as if it were non-hygroscopic.

Furthermore, if a cargo of refined sugar is ventilated, the temperature fluctuations created can lead to caking of some of the sugar in the stow. Therefore, refined sugar in lined bags should never be ventilated.

EQUIPMENT FOR MEASURING THE DEW POINT

The most commonly used equipment to measure the dew point is the psychrometer.

Aspirated (whirling) psychrometer

The traditional method of obtaining the dew point is by taking wet-bulb and dry-bulb temperatures, then using these temperatures to read off the dew point from tables.

There should be little difficulty in measuring the dew point of the atmosphere. A set of thermometers is hung in a Stevenson screen on the bridge wing, and the temperatures can be read directly. Care should be taken to hang the screen on the windward side, and it is important to ensure that the reservoir of the wet-bulb thermometer is kept topped-up (preferably with distilled water) so that its wick remains moist. Otherwise, determining the ambient dew point should be straightforward.

However, obtaining the dew point of the air in the hold is more problematic. A device called an aspirated (or whirling) psychrometer is still frequently used on board ships today (Fig. 21). The psychrometer comprises a

Fig. 21. **Measuring hold air dew point with a whirling or battery-powered psychrometer requires users to enter an unventilated hold. Full precautions for entry into an enclosed space must be taken**

wooden frame, in which the wet-bulb and dry-bulb thermometers are firmly fixed, together with the reservoir for the wet bulb. This frame is mounted on a handle and is free to rotate.

To use the whirling psychrometer, as its name suggests the user holds it above their head and whirls it around so that the thermometer frame rotates rapidly around the handle. This creates the necessary current of air over the wick of the wet bulb. The psychrometer should be whirled until the wet-bulb thermometer gives a steady reading. The dew point can then be read from tables.

Note that there are separate tables for use with the aspirated psychrometer and the Stevenson screen on the bridge. The correct table should, of course, be used, although in practice the difference between them is small.

There are various difficulties associated with using an aspirated psychrometer in a ship's hold. The first is that it is necessary for a crewmember to enter the hold to use it. This may be difficult, or even impossible, if the hold is fully loaded. It may also be unsafe; the procedures for entering enclosed spaces should always be properly followed.

Frequently, a cargo will be fumigated on completion of loading, and the holds sealed for fumigation to continue in transit. If it is, the provisions of the IMO Recommendations on the Safe Use of Pesticides in Ships Applicable to the Fumigation of Cargo Holds should be followed. Among other things, these state that the crew should only enter such a hold in an extreme emergency. Clearly, the crew should not enter fumigated holds to obtain temperature readings.

Even assuming the hold can be safely entered, the procedure is still not straightforward. In the first place, the ventilation must be shut off, since it is the dew point of the air in the hold, and not of the ventilating air, which is to be measured.

If ventilation has been suspended overnight, then the ideal time to take measurements is in the morning, before ventilation is resumed. However, when ventilation has been suspended for such a long period, great care should be taken to ensure it is safe to enter the hold.

Battery-powered psychrometers

There are various battery-operated psychrometers commercially available, and the basic advantage of these is that they eliminate the need to whirl the psychrometer around. Instead, air is mechanically drawn into the psychrometer and passed over the wet bulb or otherwise sampled. While some of the cheapest and most basic models simply show the wet-bulb and dry-bulb temperatures (just as in the aspirated psychrometer), the more sophisticated equipment can display relative humidity and dew point.

Battery-powered psychrometers are easier to use. Since there will always be a temptation to cut short the whirling of the manual version, the battery-operated models may also be more accurate and reliable.

However, they do not resolve the basic problems. First, unless they are capable of remote sampling, it will still be necessary to enter the hold to use them. Second, it is still necessary to ensure that it is the dew point of the air in the hold they are measuring, and not that of the ventilating air.

MYTH OR TRUTH?

Seafarers often apply rules of thumb on when to suspend ventilation of the vessel's holds. Traditionally, ventilation has been stopped when:

- it is raining
- there is mist or fog
- the vessel is shipping seas or spray
- at night.

Suspension of ventilation in rain

It is usual to suspend ventilation when it is raining for fear that rainwater will be drawn into the ventilators and the cargo will become wetted. This would of course be the exact opposite of what the ventilation is intended to achieve.

However, it is perfectly possible for it to be raining at a time when either comparison of dew points or the three-degree rule indicates it is appropriate to ventilate. This poses a dilemma for the crew. If they do not ventilate, they run the risk that sweat will form and damage the cargo. By contrast if they do ventilate, they may wet the cargo by ingress of rainwater.

The answer for the prudent master is to assess which presents the greater risk. Among other things, this will depend upon the design of the ship's ventilators and how heavy the rain is.

If the ventilators are of the type commonly known as mushroom cowls (Fig. 22), then there is little possibility that rain will enter them, however heavy it may be. If, however, the vessel has another common type, where the inlet is mounted

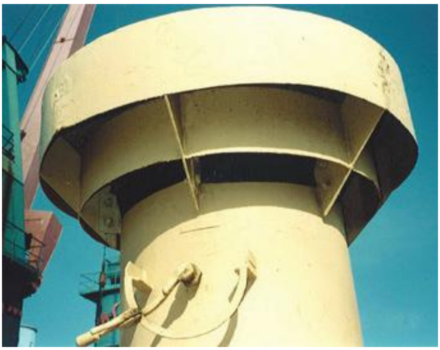

Fig. 22. **Mushroom cowl ventilators provide an effective barrier to rain**

Fig. 23. **Ventilators with vertical openings closed by a hinged door are a risk to cargoes, particularly if left open in heavy rain**

vertically on the side of a mast house or crane platform and protected by a hinged door, then there is a risk of significant quantities of water entering, particularly if they are left open in heavy rain (Fig. 23).

The risk of shipping water down a ventilator must be balanced against the risk of sweat formation. This risk will increase with the greater the temperature or dew-point differential between the outside air and that in the hold.

It is impossible to give advice which will cover every situation. As a general rule, the crew should be familiar with the ventilation arrangements on their vessel, and the degree to which they are likely to admit rainwater into the holds. Likewise, they should consider how heavy the rain is, and whether it is likely to become heavier.

If they are left in any doubt, then it is probably wiser to suspend ventilation since, if they do not and the cargo is damaged by rainwater, it will be difficult to defend any resulting claim. By contrast, if the crew suspend ventilation owing to rain, and if they correctly log this, then they are in a position to demonstrate that they acted prudently.

Suspension of ventilation in mist and fog

With mist or fog, the answer is simple. So long as either the comparison of dew points or the three-degree rule indicates that ventilation is appropriate, then the cargo may safely be ventilated.

The presence of mist or fog in the atmosphere should not cause sweat to form where it would not otherwise have done in the absence of ventilation.

Suspension of ventilation when the vessel ships seas or spray

It is normal to suspend ventilation under these circumstances. If the spray is light, and the ventilation inlets are mounted high above the deck, it may be possible to continue ventilating, but otherwise ventilation should be suspended.

Ingress of seawater into the holds by way of the ventilation ducts must be avoided. Again, the relevant log entries should be made.

Suspension of ventilation at night

The three-degree rule says that, when the outside temperature is at least 3°C below that of the cargo, the master may ventilate. Anywhere where there is a wide temperature difference between day and night, this is most likely to be met at night (and that, if it is met in the daytime, it is likely that it will also be met at night).

On the face of it, far from it being suspended at night, that will often be the time when ventilation is most appropriate. So why is ventilation almost always suspended overnight?

One traditional reason appears to be that the night-time is associated with the formation of dew, and there is presumably a fear that, in a similar way, sweat could form in the hold if ventilation were carried out by night. This is wrong and arises from a misunderstanding of what causes dew. Remember, the rules apply equally by night as by day. If the rules indicate that it is appropriate to ventilate, then the fact that the sun has set does not alter this.

There is, however, another and more valid reason why it may be prudent to suspend ventilation at night. As discussed above, ventilation will normally be suspended if a vessel is shipping seas or spray and, depending upon the severity of the rain and the design of the ventilation system, it may also be necessary to suspend it during rain.

By day, the officer of the watch should be able to assess the weather conditions and decide, in adequate time, whether it may become necessary to suspend ventilation. There should also be available sufficient personnel to close the ventilator doors, screw down the flaps, or do whatever else is required to close down ventilation and prevent water from entering.

By night, this may not be so easy. For a start, the duty officer will not be able to see as well in the dark. Rain may show on the radar screen, but it may not be readily apparent on a dark night that, for example, the vessel has started to ship spray forward. Furthermore, even if the officer receives fair warning that conditions are deteriorating, it is unlikely there are sufficient personnel to close the ventilators in the time available.

It is impossible to give firm guidelines on this. The correct action will depend upon the prevailing conditions, the design of the ship's ventilation system, and even the availability of personnel. The officer responsible will have to consider these factors and balance the need to ventilate the cargo against the possibility of a change in weather causing ingress of water through the ventilators, resulting in damage to the cargo.

It is important to note that if ventilation is withheld at night even though the conditions were such that the ventilation rules indicated that a hold should have been ventilated, conditions during the following day may well not be such that ventilation should be applied during the daytime. It is not correct to ventilate during the daytime simply because ventilation was needed during the night but could not be applied for practical reasons.

Good weather

Ship's staff often say that they ventilated 'whenever the weather was good'. This is likely to be an inappropriate statement, since some might associate 'good weather' with high temperatures.

Chapter 5

Scientific Background

Topics covered in this chapter

Air, moisture and relative humidity

Relative humidity and dew point – an example

How much condensation is produced?

Hygroscopic cargoes

Scientific rational for ventilation

AIR, MOISTURE AND RELATIVE HUMIDITY

Air is made up of nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), moisture (H_2O), and a number of other minor constituents at low concentrations. Nitrogen and oxygen together constitute over 98%.

Unlike the other constituents, the amount of moisture or water vapour which can be held by air depends on the temperature of that air. There is a maximum amount of moisture which can be present as vapour in air at any particular temperature. In fact, the relationship is exponential, which means that increases in temperature produce ever increasing capability of the air to hold moisture.

The amount of moisture which can be held by air can be expressed in two ways. To illustrate this, consider a certain volume of air at a known temperature with a given amount of moisture in it.

Firstly, it is possible to measure the mass of moisture in a given volume of air. This mass can be expressed as a proportion of the mass of the air or in relation to the volume. At any given temperature, there is a limit to how much water vapour can be in the air and this can be measured. The maximum amount of moisture is referred to as the saturation moisture content. Table 1 is an example of such data, with the saturation moisture content expressed in grammes of water per cubic metre of air, and the information is plotted in Fig. 24.

A second method is to measure what proportion of the atmospheric pressure exerted by the air in question is exerted by the moisture. Air pressure is caused by collisions of the constituent molecules in the air. Just as a proportion of the molecules are water molecules, so also a proportion of the collisions in a certain period of time involve water molecules. Therefore, it is possible to consider the proportion of atmospheric pressure which is caused by the moisture in the air. That is the partial vapour pressure of that air and is closely related to the number of water molecules in the air, and hence is closely related to the 'mass of moisture in a cubic metre' way of measuring absolute humidity.

Again, at any given temperature there exists a saturation vapour pressure for air at that temperature. This is the highest partial moisture vapour pressure which can be supported by air at that temperature. Table 2 shows how saturation vapour pressure (expressed in millimetres of mercury) varies with temperature, and the same data is plotted in Fig. 25.

The similarity between Figs 24 and 25 is no accident – the two graphs show two different ways of expressing the saturation humidity level of the air.

Table 1. **Mass of water vapour in saturated air**

Air temperature: °C	Saturation vapour mass: g/m³	Air temperature: °C	Saturation vapour mass: g/m³	Air temperature: °C	Saturation vapour mass: g/m³
0.0	4.85	17.8	15.17	35.6	40.78
1.1	5.23	18.9	16.20	36.7	43.21
2.2	5.64	20.0	17.30	37.8	45.74
3.3	6.08	21.1	18.45	38.9	48.40
4.4	6.55	22.2	19.69	40.0	51.21
5.6	7.05	23.3	20.98	41.1	54.12
6.7	7.58	24.4	22.34	42.2	57.16
7.8	8.15	25.6	23.78	43.3	60.39
8.9	8.76	26.7	25.31	44.4	63.75
10.0	9.40	27.8	26.91	45.6	67.26
11.1	10.08	28.9	28.60	46.7	70.94
12.2	10.81	30.0	30.39	47.8	74.83
13.3	11.59	31.1	32.27	48.9	78.86
14.4	12.40	32.2	34.23	50.0	83.05
15.6	13.27	33.3	36.29		
16.7	14.19	34.4	38.49		

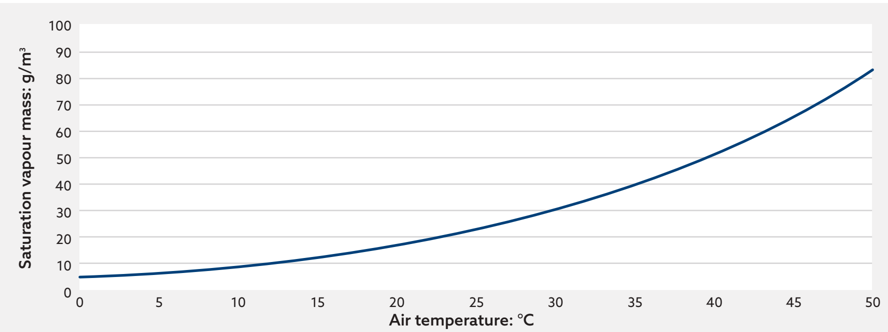

Fig. 24. **Mass of water vapour in saturated air plotted against air temperature**

Table 2. **Pressure of water vapour in saturated air**

Air temperature: °C	Saturation vapour pressure: mmHg	Air temperature: °C	Saturation vapour pressure: mmHg	Air temperature: °C	Saturation vapour pressure: mmHg
0	4.58	17	14.53	34	39.90
1	4.92	18	15.47	35	42.18
2	5.29	19	16.47	36	44.57
3	5.68	20	17.53	37	47.08
4	6.10	21	18.65	38	49.70
5	6.54	22	19.82	39	52.46
6	7.01	23	21.07	40	55.34
7	7.51	24	22.38	41	58.36
8	8.04	25	23.76	42	61.52
9	8.61	26	25.21	43	64.82
10	9.20	27	26.74	44	68.28
11	9.84	28	28.35	45	71.90
12	10.51	29	30.04	46	75.67
13	11.23	30	31.82	47	79.63
14	11.98	31	33.70	48	83.75
15	12.78	32	35.67	49	88.06
16	13.63	33	37.73		

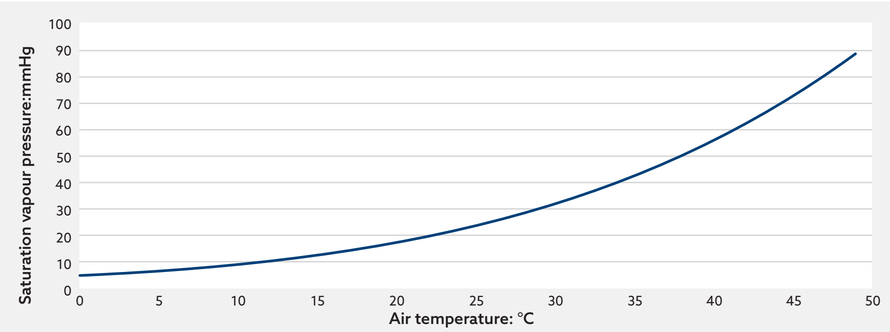

Fig. 25. **Pressure of water vapour in saturated air plotted against air temperature**

RELATIVE HUMIDITY AND DEW POINT – AN EXAMPLE

As an example of how the data can be used, let us take Table 1. This shows that at 30°C, the mass of moisture in saturated air is 30.39 g/m^3. Relative humidity can be defined as the amount of moisture which air contains expressed as a percentage of the saturation moisture content at that temperature.

To continue the example, if air at 30°C happened to contain only 20 g/m^3 of moisture, its relative humidity would be: 20/30.39 x 100 = 65.8%. Also looking at Table 1, air at a temperature of around 23°C would be saturated if it contained 20 g/m^3 moisture, and hence the dew point of air at 30°C and 65.8% relative humidity is 23°C. This demonstrates an important point.

The dew point of air at a given temperature and relative humidity is the temperature to which the air would need to be cooled to become saturated. Below the dew point, condensation occurs. Since the saturation temperature (and hence the dew point) is solely determined by the amount of moisture in the air, dew point is itself a direct measure of the amount of moisture in air. This can be further illustrated using the vapour pressure data in Table 2.

Air at 25°C has a saturation water vapour pressure of 23.76 mmHg. So, air at 25°C with 72% relative humidity would have a water vapour pressure of: 23.76 x 72/100 = 17.1 mmHg. Table 2 shows that saturated air at 19.5°C also has a water vapour pressure of 17.1 mmHg. This means that air at 25°C and 72% relative humidity has a dew point of 19.5°C. Condensation would start to take place if the air was cooled below 19.5°C.

HOW MUCH CONDENSATION IS PRODUCED?

Consider a ship's cuboid hold 30 m long, 20 m wide and 16 m deep. The volume of that hold would be 9,600 m^3.

Suppose some type of non-hygroscopic cargo (for instance a cargo of dry steel with no dunnage or other plant-based material) is loaded into the hold in a tropical region. The free air volume in the hold might be something like 6,000m^3 which initially contains air at 32.2°C and 90% relative humidity after loading. Each cubic metre of air in that hold contains 90% of the amount of moisture which saturated air could carry.

Table 1 tells us that saturated air at 32.2°C would carry 34.23 g of moisture per cubic metre. Therefore, 6,000m^3 of air at 90% relative humidity and 32.2°C would contain 6,000 x 34.23 x 90/100 = 184,842 g of moisture, which is almost 185 kg.

Suppose the vessel were to sail into a region with very cold ambient conditions, which resulted in all the air in the hold cooling to 0°C. Saturated air at 0°C can only hold 4.85 g of moisture per cubic metre, according to Table 1. This means that the 6,000 m^3 of air in the hold, which is now all at 0°C in our rather extreme example, can only be holding at most 6,000 x 4.85 x 100/100 = 29,100 g of moisture (29 kg) even when saturated. In turn, this means that almost 156 kg of moisture must have been deposited as condensation.

Although 156 kg may sound like a lot of moisture, it would occupy only 0.156 m^3 in volume. To put this into context, our cuboid ship's hold has a surface area of 2,800 m^2, so if condensation formed equally on all six faces, the moisture would form a film of thickness 0.06 mm on the steelwork.

HYGROSCOPIC CARGOES

Hygroscopic cargoes are those which have an inherent moisture content which can interact with the atmosphere. This includes virtually everything which has, at some stage, been grown – such as all grains and oilseeds, animal feedstuffs, timber and its products, and so on.

When hygroscopic material is placed into an enclosed space, the material tends gradually to absorb moisture from or desorb moisture to the air in the space. For any cargo at a given temperature and with a certain moisture content, there is a relative humidity level at which it will be in equilibrium with the air in contact with it.

At equilibrium, there is no net transfer of moisture into or out of the cargo. If the air is drier than the level which would be in equilibrium with the cargo, moisture will move from the cargo to the air until it reaches equilibrium. Conversely, if the air has more moisture in it than the equilibrium level for the cargo, moisture will move from the air into the cargo until equilibrium is reached.

The reality therefore is that significantly more condensation would occur if a hygroscopic cargo were loaded at 32°C and the external ambient conditions then became sufficiently cold to cool the air in the hold all the way down to 0°C than would occur in the above example with a non-hygroscopic cargo.

Significant wetting can occur with much less extreme temperature conditions. This is because, although cooling the air in a hold is the direct mechanism by which condensation occurs, by far the greater part of the moisture in a hold containing hygroscopic cargo is associated with the cargo itself rather than the air in the hold when the cargo was loaded. Typically, agricultural-type cargoes contain more than 10% moisture by mass, and so even a modest amount of such cargo contains tonnes, rather than kilogrammes, of moisture.

Our cuboid ship's hold could carry over 5,000 t of grain, which would contain over 500 t of moisture. This is over two thousand times as much moisture as is present in the air in the empty hold under warm and humid conditions. This provides a reservoir of moisture which can replenish the moisture in the air on a continual basis and allow condensation to occur effectively on a continual basis when ambient conditions are conducive. To return to the bathroom mirror example, the shower is permanently on.

Similarly, the temperatures within a closed hold containing hygroscopic dry bulk cargo are conditioned by the cargo, the bulk of which changes only very slowly in response to air temperature fluctuations, even if ventilation is being carried out.

That is why the loaded temperature of the cargo plays an important role in governing how the cargo will behave during a voyage. Not only is the shower permanently on, but it has a virtually endless supply of hot water.

SCIENTIFIC RATIONALE FOR VENTILATION

At its most basic, ventilation is simply a process of exchanging some of the air in the hold with air taken from outside the vessel. This should always be borne in mind, and with this concept, the question of whether to ventilate becomes a question of whether it is preferable to retain the air currently in the hold or whether introducing outside air would be beneficial, or at least harmless.

It is worth stressing that, although many cereal cargoes are alive in the sense that the seeds have the capability of germinating under the correct conditions, no bulk or bagged agricultural commodity actually needs a supply of fresh air for it to 'breathe'. This is in marked contrast with many fruit and vegetable cargoes which may require both refrigeration and fresh air exchange to prevent the build-up of carbon dioxide gas from the respiration of the commodity.

Ship's sweat

Significant ship's sweat formation is a risk with a hygroscopic cargo that is inherently warm and is carried through cool climates. The process, as described above, is that the air in the hold becomes cooled by the influence of the outside air on the ship and, once the air is below its dew point, condensation can start to form on the metal structures of the ship. This may then drip or run onto the cargo, wetting it.

The solution is to provide ventilation to the cargo space – simply replacing the air in the headspace above the cargo with colder air from outside will reduce or eliminate the risk of condensation forming on the steel.

Cargo sweat

Cargo sweat in the classic sense occurs when an inherently cold cargo is subjected to air which is warmer and has a dew point in excess of the cargo temperature. This may occur if a cold cargo is erroneously ventilated with warm moist air, and it may also occur (for example) during discharge of an inherently cold cargo in a tropical port.

Therefore, the only situation where ventilation of a hygroscopic cargo can be beneficial is when conditions are such that ship's sweat is likely – when an inherently warm cargo is carried to a cool region.

Moisture migration

It is often pointed out that when ambient conditions are substantially cooler than the cargo temperature (and hence significant ship's sweat is likely), prolonged ventilation will eventually cool accessible cargo. This is true, especially for cargo at the top of a hold.

The remainder of the cargo will be much slower to change in temperature, and so conditions may be set in place whereby some of the cargo at the surface of a stow is at a lower temperature than interstitial air in contact with the bulk of a stow. This could create a type of cargo sweat in which moisture from the bulk of a stow, which has remained inherently warm, can condense in or on cargo in the periphery of the stow which has been cooled by ventilation applied in an attempt to prevent or mitigate the effects of ship's sweat. This is a form of moisture migration, and this consideration leads to the question of whether it is correct to ventilate under such circumstances.

The answer this lies in the moisture relationships of the air as discussed earlier in the guide. By definition, whenever there is a risk of ship's sweat formation, the dew point of the air in the hold if not ventilated would have to be below the temperature of the external air.

Dew-point rule

The dew-point rule involves comparing the dew point of the air inside the hold with the dew point of the ambient air outside. As discussed earlier, dew point is one way of measuring how much moisture is in the air – air which has a low dew point has less moisture in it than air with a higher dew point.

Therefore, the dew-point rule is actually a comparison of how much moisture is in the air in the hold when compared to the amount of moisture in the external air. Put another way, if the dew point comparisons tell you that the air outside has a lower dew point than the air inside, the outside air contains less moisture than the in-hold air.

If the outside air is much cooler than the inherent temperature of a large bulk of the cargo, then a cubic metre of outside air contains less moisture than a cubic metre of air associated with the cargo. Although there may be a risk, if conditions really are that extreme, of condensation forming in a layer in the periphery of the stow once that periphery is cooled, the act of ventilating under those circumstances has led to there being less moisture in the hold atmosphere. This is clearly advantageous when it is considered that the moisture which would be removed by ventilation would condense and most probably end up wetting the cargo if ventilation were not applied.

The very real difficulties involved in taking reliable dew point measurements in a hold were discussed in Chapter 4. It is worth revisiting the fundamental problem inherent in taking dew point measurements, which is that if conditions are conducive to ship's sweat, the vessel should, by definition, be ventilating if that is possible. This of course means that any attempt to measure the dew point in a hold will measure the dew point of the ventilating air unless ventilation is arrested for the purposes of taking the reading.

It will take time for the temperature and humidity of the air within a hold containing hygroscopic cargo to stabilise after ventilation has ceased. Obviously, the greater the temperature difference between the cargo in the hold and the ventilating air, the longer it will take for conditions within the hold to return to baseline after ventilation has ceased.

How long should ship's staff wait before taking a dew-point measurement? In the meantime, is there a risk of ship's sweat formation? There is no simple answer to these questions, which is why the three-degree rule is also discussed.

Three-degree rule

The three-degree rule is derived from the dew-point rule in a simplified form. It assumes that the bulk of cargo in a hold will remain at or near its loaded temperature. This is usually true. The circumstances under which it may not be true are discussed below.

It is a long-established fact that the air around sea level in the open oceans always has a relative humidity of around 80%. Consideration of Table 1 or Table 2 shows that at temperatures between 0–30°C, air with relative humidity 80% has a dew point 3–4°C below the temperature of the air. For example, air with temperature 20°C above the ocean will have a relative humidity of around 80% and a dew point of 16.5°C.

Again, on the assumption that the bulk of a hygroscopic cargo such as grain will retain its loaded temperature, it will influence the air in a hold which is not being ventilated. Agricultural commodities which are dried prior to shipment to prevent microbial spoilage during transit will tend to condition the air to an equilibrium relative humidity level of around 70% or less. Therefore, if a hold were to remain unventilated, the eventual equilibrium situation would result in the air in the hold being at or around the loaded cargo temperature, and around 70% relative humidity or less.

Consideration of Table 1 or Table 2 shows that air at 70% relative humidity between 0°C and 30°C will have a dew point some 5–7°C below the air temperature.

Putting these two considerations together, if the loaded cargo temperature is around 3°C above the ambient air temperature, the dew point of the air inside a non-ventilated hold will be similar to the dew point of the ambient air. If then the ambient air is 3°C or more below the loaded cargo temperature, the dew point of the air in the hold will be similar to, or greater than, the dew point of the ambient air, and ventilation should be applied.

Although the three-degree rule may appear to be simply a convenient rule-of-thumb, it does have a solid scientific foundation.

If an inherently warm cargo is carried to a much cooler region, clearly the three-degree rule will indicate that ventilation should be applied. If ventilation with very cold air is applied to a bagged cargo for an extended period of time, there may come a point where substantial amounts of the cargo will have reduced in temperature as a result of the ventilation. Under such circumstances, the assumptions underlying the three-degree rule are no longer valid.

It is stressed, however, that the three-degree rule may be safely used for even the longest ocean voyages, and this could only become problematic if an extended delay takes place and ambient temperatures stay low for some time and then increase.

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Cargo Ventilation

A GUIDE TO GOOD PRACTICE
Second Edition

David Anderson, Daniel Sheard and North P&I Club

This unique illustrated guide for masters, ships' officers and others associated with the carriage of cargo explains how to avoid problems and disputes arising from incorrect use of natural and mechanical hold-ventilation systems on cargo ships.

Incorrect use of ventilation can lead to cargo damage from ship's sweat, cargo sweat, rainwater or seaspray. The guide addresses the key cargo ventilation questions of why, when, what and how, with particular emphasis on the application and pitfalls of the dew-point and three-degree rules.

The guide works on various levels, with a quick reference section supplemented by practical guidance and considerations, plus a scientific background for those wishing to understand the underlying principles.

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Brookes Bell
Brookes Bell is a leading multi-disciplinary technical and scientific consultancy serving the marine and energy sectors. It investigates, surveys, troubleshoots and advises on a broad range of marine and energy matters including casualty investigation, litigation support, salvage and wreck removal, design support, scientific cargo expertise, superyacht services, bespoke software products and energy and marine loss adjusting.

North P&I Club
North is a leading global marine insurer with over 160 years history in the industry. Its primary purpose today remains as it was on its inception in 1860: to enable its shipowner and ship operator members to trade with confidence. Its targeted loss prevention initiatives provide members with information, support and guidance to help them avoid having to make a claim, and to equip them with the right tools to help shape their own internal programmes.