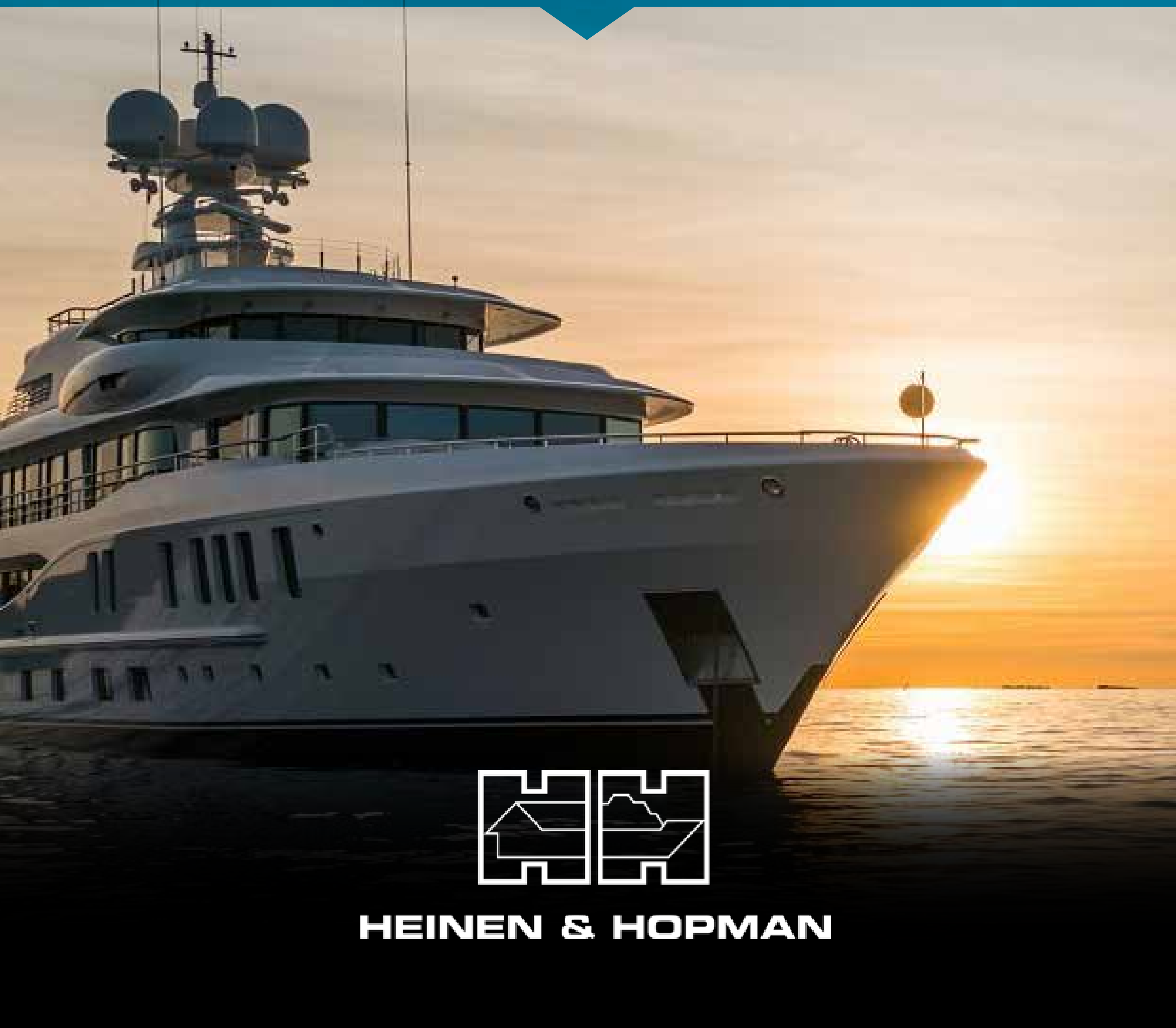
OUTSIDE CONDITIONS

HOW DO THEY AFFECT THE WAY WE DESIGN OUR HVAC SYSTEMS?



HEINEN & HOPMAN

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Do you know what you prepare for?

INTRO

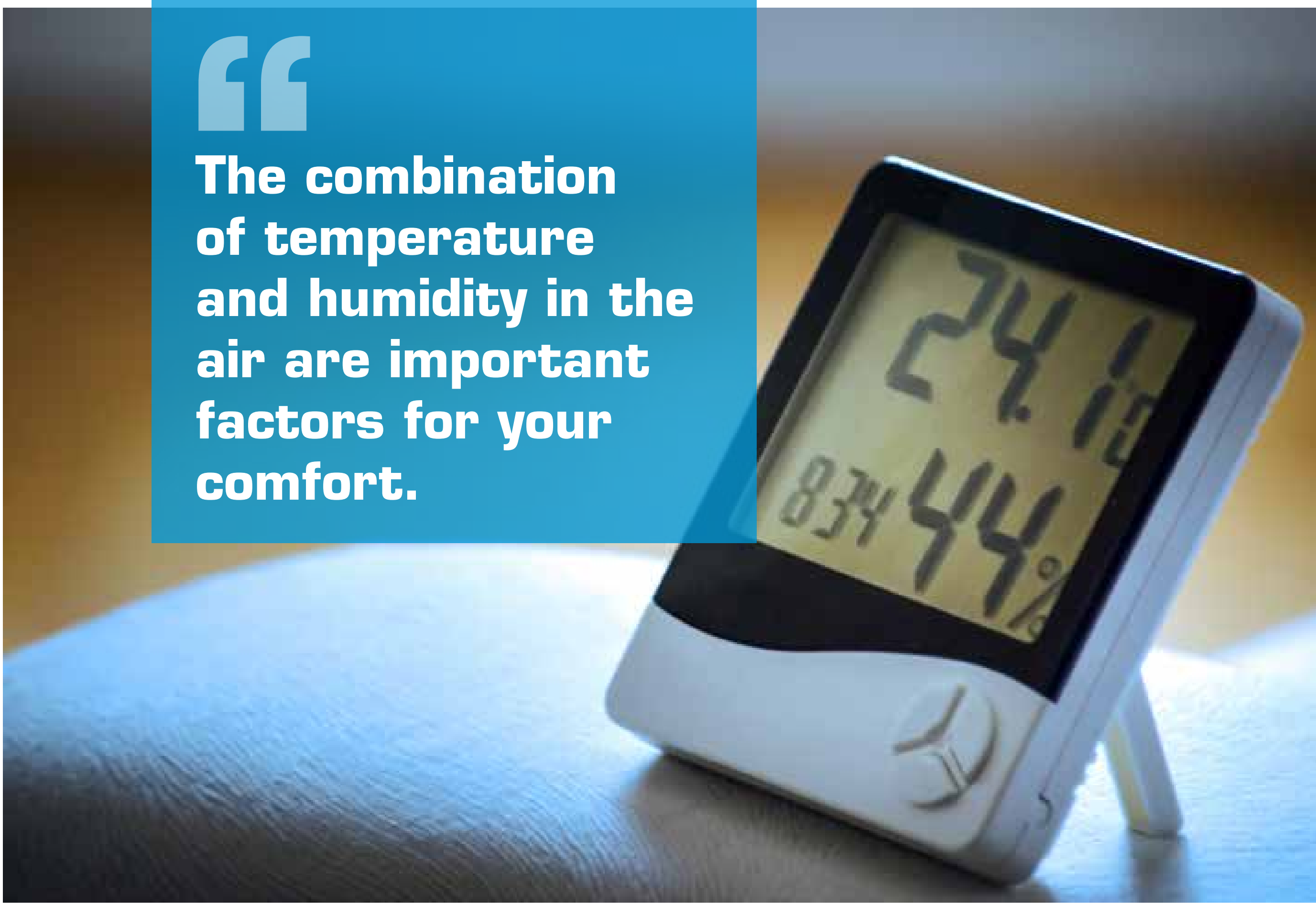
The sun has been shining all day, but as the evening comes, suddenly a short burst of rain falls. Then, for a short period afterwards the air around you feels warmer.

Why would cold raindrops make the air feel warmer?

This is a good example on how the combination of temperature and humidity affect our sensation of the air around us.

The short explanation for this is that the rain drops quickly evaporate, increasing the humidity of the air while not reducing the temperature too much. As a result, the enthalpy of air increases. The engineering concept of enthalpy and realistic outside conditions are some things we will explore in this whitepaper.

> **The combination of temperature and humidity in the air are important factors for your comfort.**



CHAPTERS

SUMMARY

As a ship travels around the globe it experiences a great variety in outside conditions. All from searing hot to ice cold, very dry to extremely humid. But are these extremes as extreme as we think? And how do they affect the way we design our HVAC systems?

This whitepaper is about how the outside conditions affect the demand on an HVAC system. Through five sections we will discuss what moist air really is, a working definition of enthalpy, relation between moist air and enthalpy, then what realistic outside conditions we may encounter and finally look at problems with a wrongly specified HVAC system.

By exploring the topic of outside conditions, we will give you a better understanding of:

- The properties of moist air
- What is enthalpy and how does it affect the demand on an HVAC system?
- How does temperature affect humidity and vice versa?
- Where do we find the most demanding outside conditions, why one region sticks out from the rest and how demanding are these conditions really?
- Based on historical weather data, how should one specify temperature and humidity for an HVAC system for a ship?

> How demanding are these conditions really?

PART 1
THE PROPERTIES OF MOIST AIR

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WHAT IS MOIST AIR?

Even though the air around us is mostly composed of nitrogen and oxygen it also contains fractions of other gases such as argon, carbon dioxide and water vapor. With HVAC systems we are concerned about the amount of water vapor present in the air and the temperature of the air.

RELATIVE HUMIDITY

A way to describe the amount of water vapor present in the outside air is relative humidity, which most times just is referred to as humidity and is given in percent. Just as a cup of tea can only absorb a certain amount of sugar, the air can only absorb a certain amount of water vapor. So relative humidity can be simplified down to the amount of water in the air relative to the saturation amount the air can hold at a given temperature. When the air has a relative humidity of one hundred percent and it is cooled down, the water vapor condenses, and we get liquid water.

Relative Humidity

In more technical terms the relative humidity is defined as the ratio of the partial pressure of water vapor and the saturation pressure of water vapor at the specified temperature. So, as a result of this the relative humidity is dependent on both the temperature and the partial pressure of the water vapor.

$$RH = \frac{P_v}{P_{sat}(T)}$$

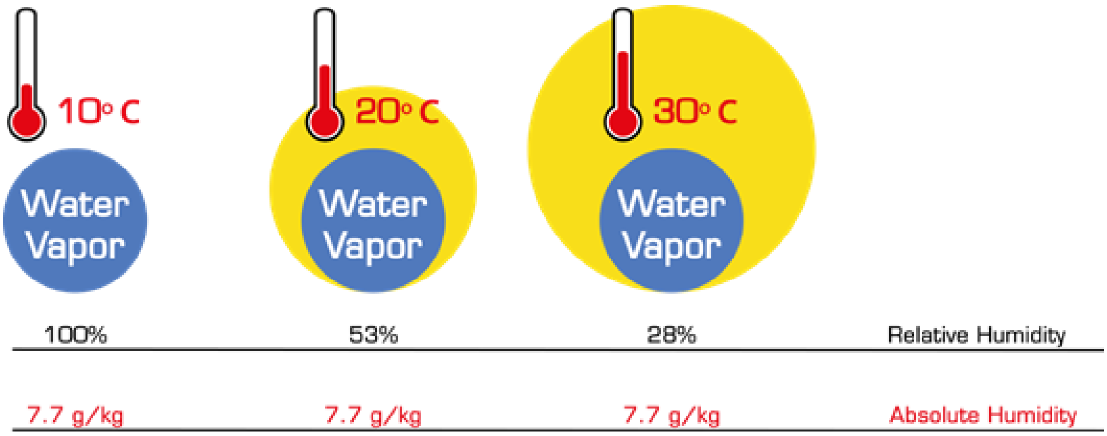

Image 1

Image 1: The blue area represents the volume of water vapor at the different temperatures, while the yellow area represents the saturation amount of water the air can hold at the different temperatures.

1 ABSOLUTE HUMIDITY

Another quantity of concern in HVAC systems is the humidity ratio or absolute humidity. This is the ratio between the mass of water and the mass of dry air.

Even though it is possible to create a large array of air with different temperatures and humidities there are certain limitations to what conditions we may find around the globe. After thorough investigation we have found that in general the temperature and humidity are inversely proportional. Therefore, when temperature is high the humidity is equally low

Humidity Ratio

The following equation can be derived from thermodynamic relations, where x then is the humidity ratio:

$$X = 0,62198 \frac{P_v}{P_{atm} - P_v}$$

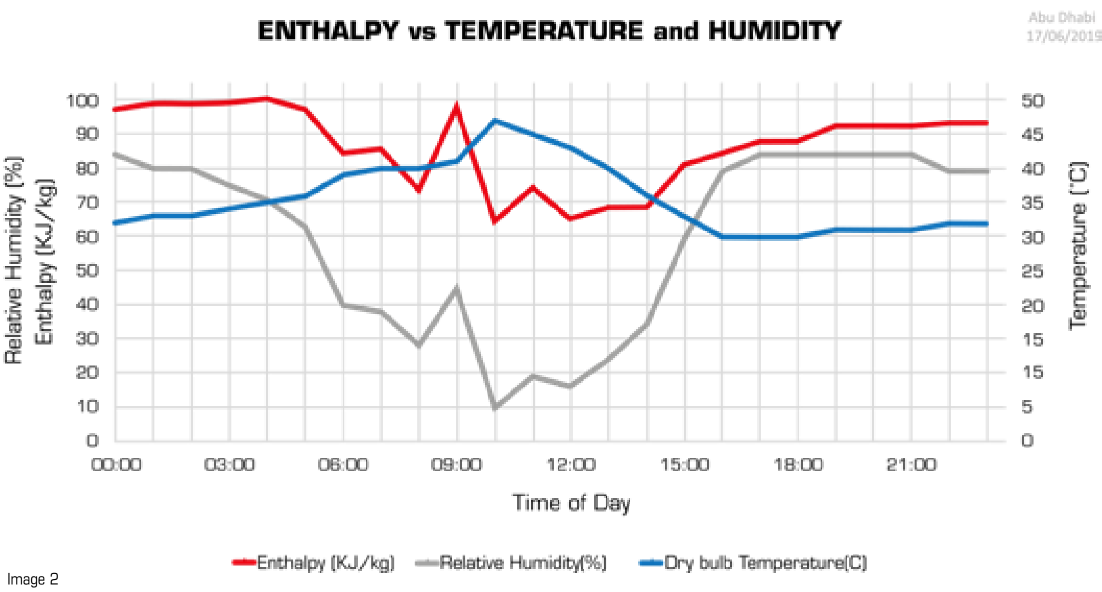

Image 2

Image 2: The chart shows the measurements of temperature and humidity done in Abu Dhabi on the 17th of June in 2019. Accompanied is the corresponding enthalpy.

“In general, temperature and humidity are inversely proportional.

PART 2

WHAT IS ENTHALPY?

PART 2

WHAT IS ENTHALPY?

LET'S DIP OUR TOES IN THE FIELD OF THERMODYNAMICS

Enthalpy is a quantity from the field of thermodynamics that allows us to quantify the amount of heat added or removed from a system. This by assuming constant pressure and referring to some base values, usually dry air at 0 degrees Celsius. The constant pressure assumption makes enthalpy only dependent on the temperature.

Enthalpy

Enthalpy of air at a specified temperature is equal to the sum of the enthalpy of dry air and the enthalpy of the water vapor present in the air.

$$h(T) = h_a(T) + h_v(T)$$

> **The heat added or removed at a constant pressure.**

Image 3

CONNECTION BETWEEN ENTHALPY AND MOIST AIR

In understanding enthalpy and how it affects our HVAC systems, it is also important to note that enthalpy differs with respect to the substance we are looking at. For moist air we are then concerned with two gases, one being dry air and the other water vapor. So, in order to find the total enthalpy of moist air we simply consider dry air and water vapor by themselves and then add their contributions together.

A better way of looking at this is by using the psychrometric chart. It may look a bit strange at first sight but it's a very useful tool. Along the horizontal axis we have the temperature, on the vertical axis on the right we have the humidity ratio, constant relative humidity lines are parabolas, and finally constant enthalpy lines are the tilted ones going from the 100% humidity line.

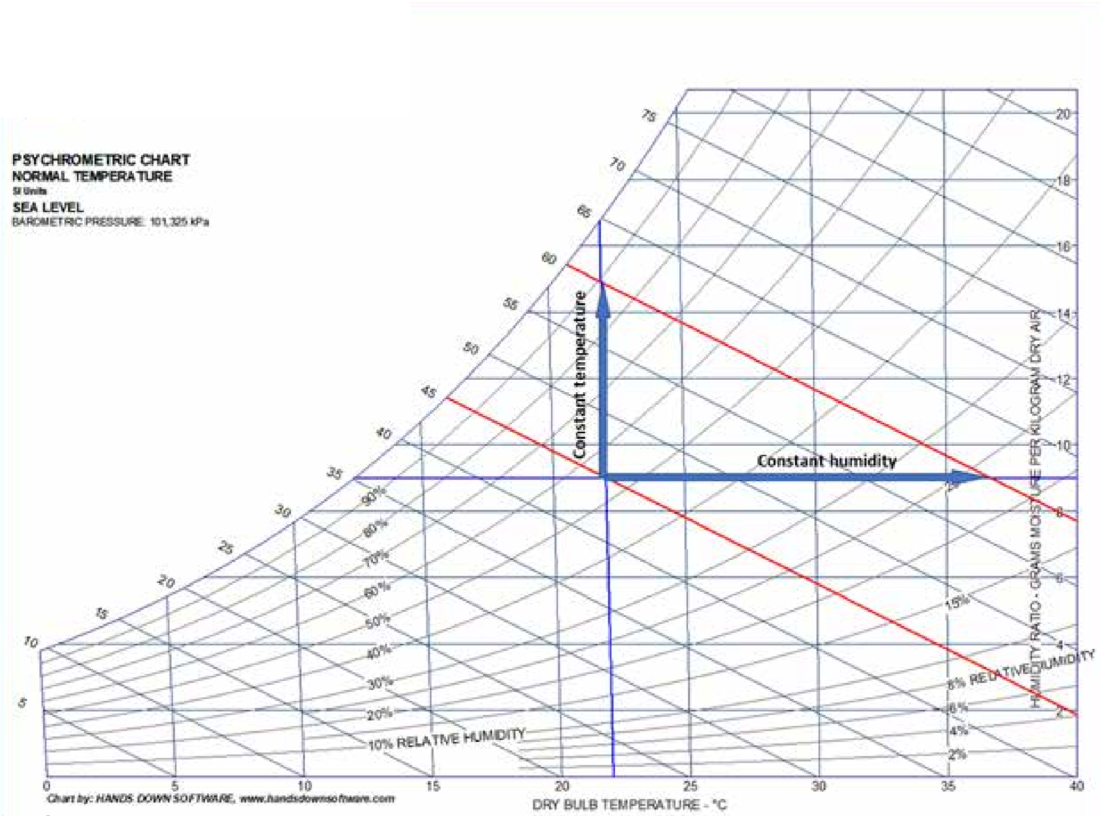

Image 3

Image 3: As seen from the chart enthalpy increases as either temperature and/or humidity increases.

3

PART 3

WHAT ARE THE MOST EXRTREME OUTSIDE CONDITIONS?

3

PART 3

WHAT ARE THE MOST EXTREME OUTSIDE CONDITIONS?

One thing everyone working with HVAC should be happy about is that meteorologist love to collect data. Due to this we have been able to look up historical weather data all around the world, and from here get a perspective on how temperature, humidity and the demand on an HVAC system varies with years, seasons, months, weeks, days and even during a day.

With an earlier study on outside conditions that we did in 2011 as a foundation, we further built our database of weather data and used the previous data to confirm that our new findings were accurate. In the study called 'Extreme ambient conditions', the scope was from 2005-2011 and twelve of the hottest harbor cities around the globe. Now we have looked at the years from 2014 to 2018 and 32 of the hottest places along the coast worldwide, but also including some inland places in the Sahara region for comparison.

Most of the weather data is based on measurements done every third hour over a five-year period. In the table below the highest occurring enthalpy values for these places are shown. We also show what the highest enthalpy value is if we shave the peak by 1%.

As one can see from the results, the Persian Gulf sticks out as the place with the most demanding conditions. This as a result of the shallow waters with an average depth of only 50 meters, and a max depth of 90 meters, which results in high water temperatures.

COUNTRY	CITY	Highest recorded ENTHALPY (KJ/KG)	ASSOCIATED TEMPERATURE (°C)	ASSOCIATED RELATIVE HUMIDITY (KJ/KG)	"1% PEAK SHAVED" ENTHALPY* (KJ/KG)
Middle East					
UAE	Abu Dhabi	109.0	38.7	62	99.5
UAE	Dubai	109.5	38.8	62	99.1
Saudi Arabia	Dammam	102.3	33.0	84	89.2
Saudi Arabia	Jeddah	99.5	37.4	59	90.3
Oman	Muscat	111.3	34.7	84	100.8
Qatar	Doha	108.8	34.4	83	101.0
Kuwait	Kuwait	105.3	34.1	81	87.6
Saudi Arabia	Dhahran	122.7	44.0	52	95.5
Bahrain	Airport	122.6	36.3	86	100.1
Asia/Oceania					
Sri Lanka	Colombo	96.6	31.2	88	86.7
Singapore	Singapore	88.4	28.6	94	84.5
Indonesia	Balikpapan	97.4	30.9	91	86.8
Philippines	Manila	99.6	31.8	88	89.5
Indonesia	Jakarta	92.4	33.8	68	83.7
Indonesia	Makassar	100.2	30.7	96	90.2
Australia	Darwin	92.0	32.8	73	85.5
India	Mumbai	97.3	36.0	63	88.7
Caribbean					
Cuba	Havana	86.6	32.7	67	79.2
Curacao	Willemstad	89.5	32.8	70	84.7
USA	Miami	89.0	31.7	75	83.2
Mediterranean					
Greece	Athens	79.0	33.8	53	68.3
Egypt	Alexandria	85.0	27.3	98	75.5
France	Nice	83.7	29.5	81	70.8
Portugal	Lisbon	69.6	43.0	19	59.9
Algeria	Alger	96.2	34.5	69	79.1
South America					
Brazil	Manaus**	83.3	30.6	74	77.7
Brazil	Fortaleza	88.8	31.0	79	80.2
Peru	Chiclayo	88.1	27.7	100	75.4
Africa					
Egypte	Abu Simbel	82.4	34.0	56	66.1
Ghana	Accra	94.8	29.5	97	86.5
Niger	Bilma	91.0	43.0	34	75.0
USA - West Coast					
USA	Los Angeles	73.5	36.0	39	61.8

Values based on weather data from the years 2014-2018.
Table showing highest recorded enthalpy and associated temperature and relative humidity. Both temperature and relative humidity can be higher, but not in a combination giving higher enthalpy.

* The 99th percentile enthalpy – meaning the highest after having removed the top 1% of measurements done over the five year period.

** Only one year of data (2018)


Los Angeles
Miami
Havanna
Curacao
Manaus
Chuclayo
Fortaleza
Lisbon
Nice
Accra

Athens
Dammam
Daharan
Kuwait
Bahrain
Alexandria
Doha
Mumbai
Jeddah
Dubai
Manilla
Abu Simbel
Singapore
Muscat
Abu Dhabi
Balikpapan
Colombo
Makassar
Jakarta
Darwin

CONCLUSION

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While we have both high temperatures and high humidity around the world, an important result from our study is that they don't occur at the same time. A temperature of 45˚C is never accompanied by a humidity of more than 50%, and a humidity of 95% is never accompanied by a temperature higher than 35˚C.

Around these two conditions is the highest enthalpy value we found, which was 122 kJ/kg. But this is an extreme value and is not representative for outdoor conditions an HVAC system will face. By ignoring only ten of the highest enthalpy values for each location, recorded the last five years, the highest enthalpy is 109 kJ/kg.

A typical approach for designing an HVAC system is to have a big enough cooling capacity to hold inside conditions for approximately 99% of the running time within a year. By this approach our highest enthalpy becomes 101 kJ/kg. It is also worth to note that all these values occur within a relatively small geographical area, namely around the Persian Gulf. Outside of the Persian Gulf the highest recorded enthalpy is 100 kJ/kg.

Record enthalpy & Alternative outside conditions with corresponding enthalpy

Record enthalpy

Record enthalpy	Worldwide	Outside Persian Gulf
Highest	122.7 kJ/kg	100.2 kJ/kg
Highest - After removing 10 measurements	109.0 kJ/kg	94.9 kJ/kg
99th percentile	101.0 kJ/kg	90.2 kJ/kg

Alternative outside conditions with corresponding enthalpy

	Primary conditions		Secondary conditions	
Enthalpy	Outside air temperature	Relative humidity	Outside air temperature	Relative humidity
110 kJ/kg	35°C	80%	45°C	40%
100 kJ/kg	33°C	80%	45°C	35%
90 kJ/kg	31°C	80%	45°C	29%

"The Persian Gulf sticks out as the place with the most demanding conditions.

PART 4

THERE ARE MANY GOOD REASONS FOR SELECTING CORRECT OUTDOOR CONDITIONS

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Why is it so important to know what realistic outside conditions we may encounter? While an underdimensioned system is a problem, an overdimensioned system can also be an issue. We often see systems designed for conditions well above what is ever recorded. This is done to be on the safe side, but it also has some negative consequences:

- Building too large plants
- Unnecessarily high costs
- Using too much materials
- Taking up too much space
- Bringing on too much weight to the ship.

UN Sustainability goals

In 2015, UM member countries adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals.

One of these goals is "Responsible consumption and production". In the Heinen & Hopman group we emphasize to develop systems that target this goal both in the construction of the ship and throughout the lifetime of the plant.

4

ENERGY CONSUMPTION

As a company we are always looking for new and innovative solutions to make our systems better. One aspect of this is the energy consumption and environmental effects.

While through innovation the energy efficiency of a system can be increased - resulting in lowering the environmental effects - it is also important to not overdo the system in the first place. One of the UN's sustainable development goals is to ensure 'Responsible Consumption and Production'. In accordance with this we should all try to limit our resource use to only what is needed.

By knowing what outside conditions the HVAC system needs to be prepared for, we can use the amount of resources needed to provide indoor comfort while at the same time not use too much. This will downsize the HVAC system, reducing the energy consumption of the system.

Climate change

Changes in climate is a known challenge for the world today. It is generally acknowledged that the global average temperature will increase with a few degrees in the coming 20-30 years. It is also generally accepted that the variation will increase meaning both wind, rain and temperature could reach more extreme values than today. This should be considered when finally choosing the design conditions for the HVAC system.

United Nations
Climate Change

“

While an underdimensioned system is a problem, an overdimensioned system can also cause problems.

PART 5

THE SWEET SPOT

PART 5

THE SWEET SPOT

While an under dimensioned system is a problem, an over dimensioned system can also be an issue. It is therefore very important to determine the 'sweet spot' in terms of required cooling capacity for an HVAC system. When designing an HVAC system , we take several factors into consideration:

- Sailing program
- Technical rooms
- Cooling capacity
- Involve us as early as possible

Sailing program

In order to determine what realistic conditions are for a certain vessel, it is important to consider the sailing program. We have engineered HVAC systems for superyachts that are based in Qatar 365 days a year, but many vessels don't visit destinations with extreme outside conditions very often. It is more likely that these ships are sailing somewhere else in the few hours the maximum conditions occur. In case a vessel encounters the maximum conditions only a couple of days during the year, the HVAC system probably shouldn't be dimensioned on the maximum conditions.

Technical rooms

It is also wise to consider the required cooling capacity for technical rooms, where higher indoor temperatures don't only affect comfort, but also equipment. High temperature rises can be critical and result in equipment failure.

Cooling capacity

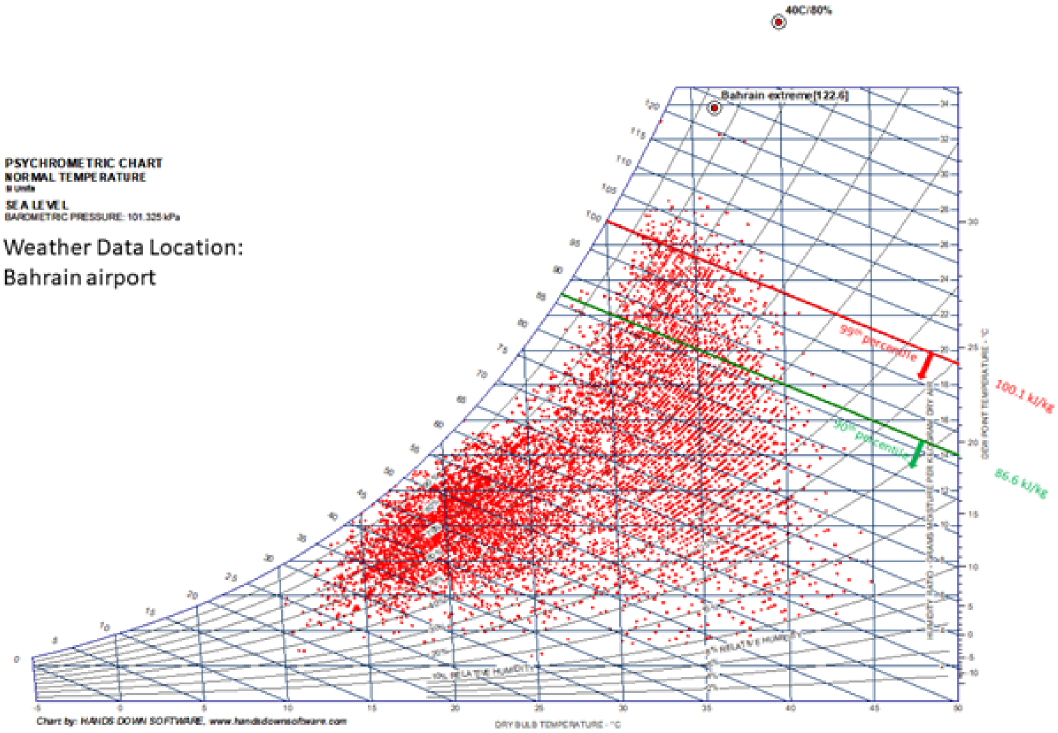
HVAC systems can be designed with some kind of redundancy or spare chiller capacity (e.g. 3x50%, 2x60%, 4x33%) in case of breakdown on compressors or other vital components. By utilizing this capacity in the few extreme situations, the indoor conditions should be held in most situations. The temperature might increase by a degree or two.

In worst case, the consequences are very often limited to indoor temperature increases slightly above designed value. It will happen seldom, and for a short period each time. It will most likely not affect safety for passenger, crew or ship operation.

Involve us as early as possible

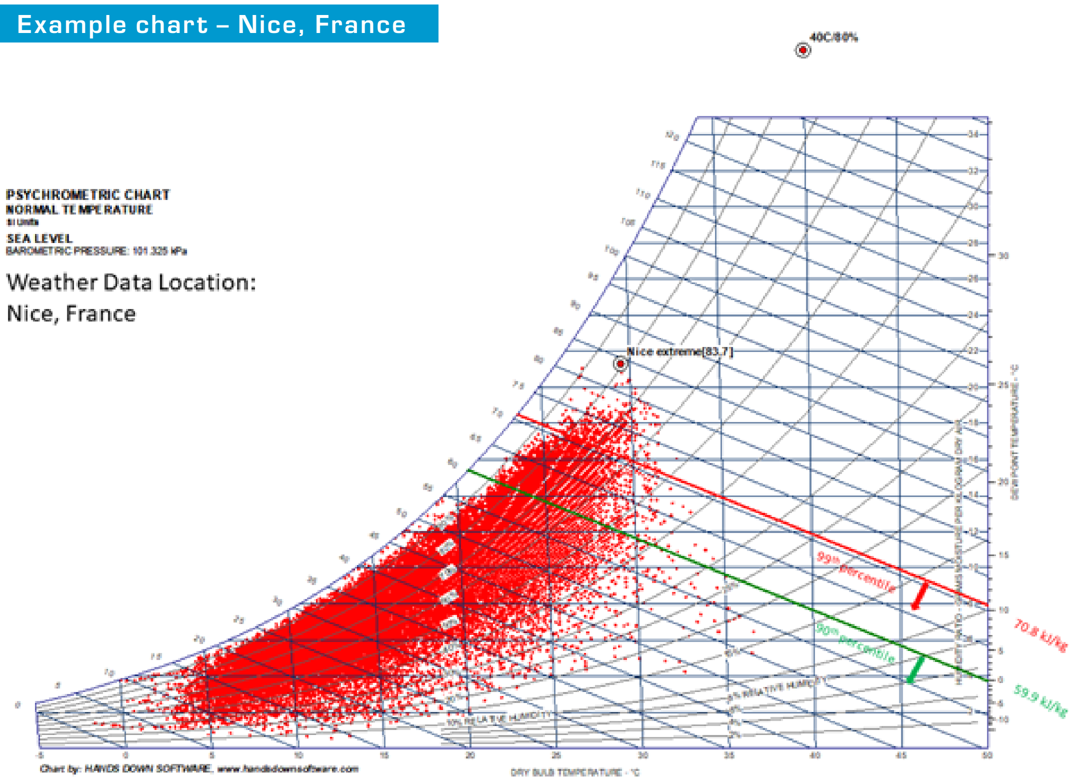
So how can we design the best HVAC system for your vessel? Involve us as early as possible. We will help you determine realistic outside conditions and dimension an HVAC system that suits your vessel and sailing program. A perfect fit for your vessel.

Example chart - Bahrain airport



The diagram shows measurements of humidity and temperature done over 5 years from 2014 to 2018 for Bahrain airport. To better show the most extreme value, they have been made bigger and accompanied by the enthalpy value. A red and green line has been put in, respectively showing the 99th and 90th percentile for all the measurements in the given locations. Some extreme dimensioning values have been put in to show how much above realistic conditions they are.

Example chart – Nice, France



The diagram shows measurements of humidity and temperature done over 5 years from 2014 to 2018 for Nice, France. To better show the most extreme value, they have been made bigger and accompanied by the enthalpy value. A red and green line has been put in, respectively showing the 99th and 90th percentile for all the measurements in the given locations. Some extreme dimensioning values have been put in to show how much above realistic conditions they are.

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Heinen & Hopman encourages a more sustainable world. By providing eco-friendly solutions and services we offer our clients the option of reducing energy consumption and thus CO2 emissions.

HEINEN & HOPMAN MANIFESTO APPROVED

“Would you like to get in touch about HVAC system design? I am keen to help you further!”

Bjørn Martin Holo -
Senior Technical Advisor
sales@heinenhopman.com

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HUMIDITY 90% 40%
22°C Inside
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