OzonAction Kigali Fact Sheet 9

Technical Issues: High Ambient Temperature

OzonAction

UN environment

Background:

The main use of HCFCs and HFCs is in refrigeration, air-conditioning and heat pump applications (RACHP). These sectors represent around 86% of the GWP-weighted use of HCFCs and HFCs (see Kigali Fact Sheet 2). It is recognised in the Kigali Amendment that designing RACHP systems for operation at extremely high ambient temperature (HAT) creates several special challenges. For air-conditioning systems, these challenges include:

a) The heat loads are higher than in milder climates

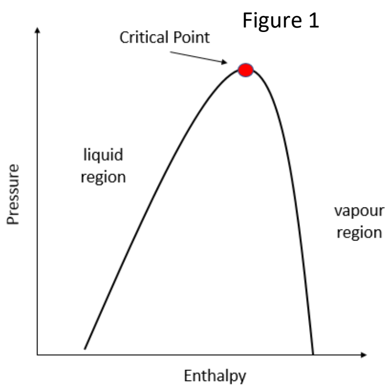
b) Heat is rejected by the air-conditioning system at a higher condensing temperature than in milder climates

These factors mean that air-conditioning systems operating at high ambient temperature need to have a greater cooling capacity for a given room size and that they use more energy than equivalent air-conditioning systems that operate in milder climates.

In this Fact Sheet some of the technical issues related to the operation of air-conditioning systems at high ambient temperature are discussed. This Fact Sheet also provides information about the HAT Exemption that is part of the Kigali Amendment.

These challenges can apply to all refrigerants:

It is important to recognise that the technical challenges related to operation under HAT conditions are not caused by the proposed phase-down of HFC refrigerants. Many refrigerants, including some of the high GWP HFCs are not ideally suited to operation at high ambient temperature. Designers of refrigeration and air-conditioning equipment have always had to take ambient temperature into account and ensure the refrigerant selected can operate efficiently and reliably. Equipment that is specified for use in countries with HAT conditions has to be designed in a slightly different way to the equipment used in milder climates. Two characteristics of the refrigerant selected are especially important:



Critical temperature. A property of all refrigerants is the "critical temperature". This is the temperature at the critical point for the refrigerant, as illustrated in Figure 1, which is a pressure-enthalpy diagram[1] for a refrigerant. For an air-conditioning cycle to have good efficiency it is important that the condensing temperature is not too close to the critical temperature. The condensing temperature is always higher than the ambient temperature, so the condensing temperature under HAT conditions will be higher than in a milder climate; hence it will be closer to the critical temperature and less energy efficient.

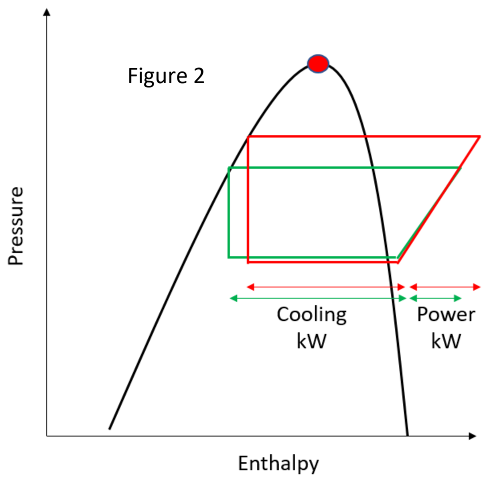


Figure 2 shows two air-conditioning cycles plotted on the diagram. The green cycle is for operation in a mild climate and the red cycle is operating at higher ambient temperature. When operating at high ambient temperature the air-conditioning system:

- does less cooling (the red cooling kW line is shorter)
- needs more electric power (the red power kW line is longer)

[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used including pressure – enthalpy diagram

This illustrates why all air-conditioning systems operating at high ambient will use more electricity than a unit running in cooler conditions.

The loss of energy efficiency becomes especially severe if the critical temperature of the refrigerant being used is low. The adjacent table lists the critical temperature of a number of refrigerants that are used in air-conditioning systems.

Refrigerant	Critical Temperature ºC
HFO-1233zd	165
R-717 (ammonia)	132
HFO-1234ze	110
HFC-134a	101
R-290 (propane)	96.7
HCFC-22	96.1
HFC-32	78.1
R-410A	71.4
R-744 (CO_2)	31.0

It is important to note that HCFC-22 has a reasonably high critical temperature. The most commonly used high GWP HFC that has replaced HCFC-22 is R-410A. This has one of the lowest critical temperatures and it is likely to perform less efficiently at high ambient temperature than HCFC-22.

For small split and ducted air-conditioning units HFC-32 has been introduced as a lower GWP alternative to R-410A – it has a GWP of 675, compared to 2,088 for R-410A. The critical temperature of HFC-32 is higher than R-410A, so a move to this lower GWP alternative will have benefits under HAT conditions. However, HFC-32 is an A2L lower flammability refrigerant (see Kigali Fact Sheet 10 for details about flammability) and it may not be applicable in larger systems in many countries.

Propane can offer high efficiency, but it is an A3 higher flammability refrigerant and can only be considered for very small systems.

R-744 has a much lower critical temperature than any other commonly used refrigerant. For air-conditioning it needs to operate as a "transcritical" cycle[2] (heat is rejected above the critical temperature). This makes R-744 less efficient and hence unsuited to most air-conditioning in HAT conditions.

The biggest challenge is for medium and large sized multi-split air-conditioning equipment, including variable refrigerant flow (VRF) systems, where a flammable refrigerant might not be applicable and where R-410A is not well suited to high ambient operation.

Larger chilled water plants for building air-conditioning pose much less of a problem. As the water chiller is usually located in a restricted access location (e.g. a special machinery room or a roof-top) it is possible to consider a range of refrigerants including flammable options such as HFO-1234ze or R-290. These have reasonably high critical temperatures which make then well suited to operation at high ambient temperature. For very large chillers, low pressure refrigerants such as HFO-1233zd are applicable. These have very high critical temperatures and can have very high energy efficiency.

Compressor discharge temperature. Another important characteristic is the compressor discharge temperature. Under HAT conditions the compressor of an air-conditioning system needs to operate across a greater pressure ratio than would occur in a milder climate. This causes the discharge temperature from the compressor to reach a higher level. In some circumstances this creates extra technical problems that can reduce the reliability of the compressor.

Very high discharge temperatures can be mitigated with extra cooling of the compressor, although this adds to capital cost and can reduce energy efficiency. It is important that designers ensure that the compressor discharge temperature remains within acceptable limits.

[2] See Kigali Fact Sheet 14 for a description of transcritical, sub-critical and cascade cycles

On-going Research, Testing and Development:

In recognition of the importance of finding a high efficiency low GWP option for air-conditioning systems, there is a lot of development work being undertaken by equipment manufacturers and refrigerant producers. There are also several independent testing programmes underway, including:

- PRAHA: Promoting low GWP Refrigerants for Air-Conditioning Sectors in High-Ambient Temperature Countries
- EGYPRA: Egyptian Project for Refrigerant Alternatives
- ORNL: the Oak Ridge National Laboratory High-Ambient-Temperature Evaluation Program for Low-Global Warming Potential (Low-GWP) Refrigerants
- AREP: the AHRI Low GWP Alternative Refrigerants Evaluation Program

These independent tests show how different refrigerants perform under HAT conditions. The latest results from these test programmes can be accessed via http://ozone.unep.org

The HAT Exemption:

The Kigali Amendment includes an exemption mechanism that can be used in countries with high ambient temperatures for certain applications that cannot use low GWP alternatives. The HAT exemption is an additional exemption process to the Critical Use and Essential Use exemptions that are included in the Montreal Protocol and could be applied to HFC applications.

Definition of HAT: For the HAT exemption to apply, a country must have an average of at least two months per year over ten consecutive years with a peak monthly average temperature above 35^{o}C[3].

Countries identified: The following countries have been assessed as meeting the above HAT definition: Algeria, Bahrain, Benin, Burkina Faso, Central African Republic, Chad, Côte d'Ivoire, Djibouti, Egypt, Eritrea, Gambia, Ghana, Guinea, Guinea-Bissau, Iran (Islamic Republic of), Iraq, Jordan, Kuwait, Libya, Mali, Mauritania, Niger, Nigeria, Oman, Pakistan, Qatar, Saudi Arabia, Senegal, Sudan, Syrian Arab Republic, Togo, Tunisia, Turkmenistan, United Arab Emirates.

Registering for the HAT exemption: to use the exemption a Party must be in the list above and must have formally notified the Secretariat of its intent to use this exemption no later than one year before the HFC freeze date, and every four years thereafter should it wish to extend the exemption.

Equipment types covered by HAT exemption:

(a) Multi-split air conditioners (commercial and residential)

(b) Split ducted air conditioners (commercial and residential)

(c) Ducted commercial packaged (self-contained) air-conditioners

Adjustment of equipment covered: the Technology and Economic Assessment Panel and outside experts on high ambient temperatures will assess the suitability of HFC alternatives and recommend sub-sectors to be added to or removed from the above list and report this information to the Meeting of the Parties. These assessments will take place periodically starting four years from the HFC freeze date and every four years thereafter.

Reporting: any party operating under the HAT exemption must report separately its production and consumption data for the sub-sectors to which the exemption applies.

[3] This definition is based on spatially weighted average temperatures deriving the daily highest temperatures, using the Centre for Environmental Data Archival: http://browse.ceda.ac.uk/browse/badc/cru/data/cru_cy/cru_cy_3.22/data/tmx

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