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Report Title	**Investigation of the MHI Q-Ton Heat Pump**
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CONTENTS

1.0 EXECUTIVE SUMMARY

The scope of this investigation covers the water hygiene / Legionella performance of the Mitsubishi Heavy Industries (MHI) Q-Ton Heat Pump.

The purpose of this report is to consider whether the Q-Ton Heat Pump represents a water hygiene risk equivalent to ALARP (As Low As Reasonably Practicable) for the three susceptibility groups – general public, healthcare/elderly/health compromised and immuno-compromised.

The investigation methods were interview, inspection of a unit on a trial site, inspection of documents and literature search.

This report is focussed on the “re-heating of circulation loop” configuration, because the majority of the market would fall into this category and because recirculating systems have a higher potential inherent risk compared to single pipe systems.

The water hygiene risk factor of relevance to the Q-Ton relative to other competitor technologies is “amplification” i.e. multiplication of micro-organisms, which this report considers.

The Q-Ton could represent ALARP in water systems serving populations of any susceptibility, subject to appropriate design, installation, commissioning, monitoring and maintenance.

One feature of the Q-Ton system which could be considered superior to other systems, is the option to store water at 90ºC or 75ºC, which provides an environment which is very adverse for micro-organisms.

It is important for MHIAE not only to control the inherent risk associated with its Q-Ton unit, but also to control and influence the risks associated with its installation, commissioning, monitoring and maintenance.

2.0 INTRODUCTION

The scope of this investigation covers the water hygiene / Legionella performance of the Mitsubishi Heavy Industries (MHI) Q-Ton Heat Pump.

The reason for existence of the Q-Ton Heat Pump is as a provider of energy and carbon savings in the production of domestic hot water. Generally one would expect the customers for such units to be capable of judging the performance and benefits of the product in terms of energy and cost savings. However such customers are less likely to have the experience, knowledge and judgement to make an assessment of whether it presents greater or less risk compared to other technologies for the production and storage of hot water, in terms of its water hygiene/Legionella performance.

The purpose of this report is to consider whether the Q-Ton Heat Pump represents a water hygiene risk equivalent to ALARP (As Low As Reasonably Practicable) for the three susceptibility groups – general public, healthcare/elderly/health compromised and immuno-compromised. In particular, this investigation addresses the issues of the avoidance of storage of tepid water and the fluctuation of temperature performance. In conducting this analysis, the investigation will make comparisons with more conventional technologies for the production of domestic hot water.

If the Q-Ton could be considered ALARP, then this investigation will go on to propose and justify performance criteria for its safe operation with respect to microbiological water quality. If Q-Ton is not judged to be ALARP for any or all of the categories of susceptibility group, this investigation will go on to outline potential modification or extras which might result in it achieving ALARP.

The scope of this investigation specifically excludes all other characteristics of the Q-Ton Heat Pump, such as:-

- Safety (this report deals only with health);
- Energy performance;
- Noise;
- Reliability;
- Other engineering and environmental aspects.

This report is not seeking to endorse or criticise the Q-Ton Heat Pump, but to provide an independent appraisal of its likely performance with respect to water hygiene. The author and the Water Hygiene Centre have no conflicts of interest and have been free to come to any conclusion based on the data available. The commission of this investigation was based on a fixed fee basis, with no financial or other incentive to produce a particular outcome. The Water Hygiene Centre does not endorse products, promote them, sell them or receive any payments or other incentives relating to their sale. The findings of this report can therefore be judged as entirely impartial.

This report has been produced for Mitsubishi Heavy Industries Air Conditioning Europe (MHIAE). If it is determined that it will be released to customers of MHIAE, then it should be communicated in its entirety, rather than selectively quoted, so as to avoid potentially damaging misinterpretations for all parties. Any future queries from customers regarding this report should be directed to MHIAE.

3.0 INVESTIGATION

Investigation Methods

The investigation methods were:-

- Interview;
- Inspection of unit on trial site;
- Inspection of documents;
- Literature search.

Principle of Operation of Q-Ton Heat Pump

The principle of operation and benefits of the Q-Ton Heat Pump are described elsewhere, e.g. in the MHI Technical Review paper "Development of the "Q-Ton" CO_2-Refrigerant Heat Pump for Industrial Water-Heater Systems for Use at Outside Air Temperatures Down to -25^{o}C".

Detail of Unit

The "Q-Ton ESA30" is capable of producing 300 litres/hour of hot water at 90^{o}C or 500 litres/hour at 65^{o}C. Greater demands for hot water can be met by the installation of multiple units. Each typically requires a storage vessel of minimum 1,000 litre capacity.

Each storage vessel has five pockets into which temperature sensors can be fitted to detect the volume (in % terms) of hot water held in the vessel at any particular time. The programming of the control system to hold specific volumes of hot water at different times of day is based on a balance of hot water demand and electricity tariffs, to ensure security of supply at minimum cost. This will necessarily vary from site to site.

The control system can accommodate up to 9 sensors on the storage vessels, e.g. two vessels with 4 sensors on each or 3 vessels with 3 sensors on each.

In larger systems more than one Q-Ton would be installed to meet demand. Each Q-Ton would require a minimum of 1,000 litre storage. If two Q-Ton Heat Pumps were required, then inevitably at least two storage vessels would be installed. Regardless of the needs of demand, in applications such as hospitals, a continuous hot water supply would be required and hence a typical installation should include at least two Q-Tons. In the event of a need for shutdown repairs to one of the units, the other would be called upon to provide the full demand requirements. Typically this would be expected to be achievable because the Q-Ton is typically sized on the basis of 10-14 hours operation per day, in order to take advantage of cheaper overnight electricity tariffs. When only one of two Q-Tons is available, it would operate for up to 24 hours/day, less economically, but for only a short period of time before the unit under repair is brought back into service. As an alternative, some installations incorporate an electric immersion heater for operation during periods of maintenance.

Unit Configuration

The presentation document provided by Herve Mariage of MHIAE describes three alternative configurations:-

- "Single Tank System" – this provides a once-through system, i.e. with no hot water return. Typical applications for this would be for a catering kitchen or sports centre changing rooms, i.e. relatively high demand, small pipework systems.

- "Modular Water Tanks" as above, but with more than one storage vessel.

- "Re-Heating of Circulation Loop" – this would be configuration for any system which has a circulating distribution system, typical of any large system, such as in hospital buildings or hotels.

This report is focussed on the latter configuration, because the majority of the market would fall into this category and because recirculating systems have a higher potential inherent risk compared to single pipe systems.

The following notes are based on the "Re-Heating of Circulation Loop" diagram, which was discussed and analysed with Herve Mariage and Hiroyuki Okada of MHIAE. A diagram from the latest installation manual, which showed more detail, was examined on a computer screen.

The Q-Ton provides hot water from a heat exchanger. Therefore one would perhaps expect it to be configured in the same way as a conventional hot water system. However, there are features of the Q-Ton which mean that an alternative configuration is adopted, for reasons of energy efficiency.

The Q-Ton seeks to provide energy, cost and carbon savings. It is most efficient when cold water is used to supply the heat pump. For that reason the cold feed water is provided to the heat pump, via the base of the storage vessel. If the domestic hot water return e.g. at 55^{o}C were used as the feed to the heat pump it would be considerably less efficient. Instead, the hot water circulating loop does not pass through the storage vessel.

The storage vessel of a Q-Ton installation is held at a higher temperature than conventional hot water storage systems. The preferred installation design is to store water at 90^{o}C, which requires a stainless steel vessel, with a higher capital cost but lower failure risk and maintenance costs. At this high temperature, micro-organisms associated with water hygiene will not survive. If the customer prefers a conventional copper vessel (or in e.g. France an epoxy lined carbon steel vessel with sacrificial anode) then water can be stored at up to 75^{o}C. The decision regarding the storage temperature is also based on the electricity tariffs (e.g. day/night) and storage volume. A conventional hot water storage system stores water at 60^{o}C.

The manner in which the Q-Ton(s) and its associated storage vessel(s) are controlled would depend on energy, cost, carbon objectives and the need to control water hygiene aspects.

Regardless of the hot water storage and delivery temperatures, there should also be an interest in the pasteurisation of the whole volume of the storage vessels at least once per 24 hours. This can be achieved by heating the whole of the contents to 60^{o}C for an hour during a low demand period. The latest design includes for the lowest sensor on the storage vessel to be located in a pocket at the base of the vessel, in the pipe serving the Q-Ton. This could be controlled to hold the full contents of the vessel at 60^{o}C or above for a period of pasteurisation.

The Q-Ton installation includes an anti-freeze circuit, which operates to prevent freezing, when the temperature of the feed water to the Q-Ton is at or below 3^{o}C. This is controlled by a three-way valve, which opens the anti-freeze circuit port when the feed temperature is low. However, for much of the time this circuit will not operate, in summer for several months, resulting in the potential for stagnation and growth of micro-organisms in the anti-freeze circuit between the three-way valve and the cold feed pipe. This could be avoided by introducing a daily timed operation cycle for this circuit.

In normal operation the hot water is drawn off from the top of the storage vessel to serve a four-way mixing valve. This blends high temperature hot water, the hot water return (typically 55ºC) from the circulation loop and cold feed water. This blend at 60ºC is delivered into the circulation loop. The cold feed water would contain very few if any Legionella bacteria and would be rapidly pasteurised by the very hot water flow. The circulation loop would be at continuous pasteurisation temperatures.

In low demand or no demand situations, there would be no draw-off from the circulating loop and therefore no call for make-up water from the storage vessel. In these circumstances the loop would lose heat and therefore temperature, unless there was an operation mode to avoid this loss of pasteurisation conditions. This has been addressed by MHIAE in two ways. Firstly, as part of the sizing exercise, each customer is provided with data describing the heat loss from the circuit, which tends to encourage the customer to improve insulation. Secondly, a temperature sensor at the four-way valve can be set to detect a temperature drop below 55ºC, at which point the hot water supply port is opened which has the effect of delivering hotter water into the circulation loop. However because this would happen at a time when there is no hot water demand, the return water is relieved via a pipe which connects to the cold feed to the storage vessel. A non-return valve on end of this pipe prevents any back flow into the circulation loop.

WRAS Approval of Non-Metallic Components

In common with any domestic water system component, WRAS approval of non-metallic components would be required for any materials in contact with water, introduced as part of the Q-Ton installation. The WRAS approval of the ESA 30 E Heat Exchanger has been issued under certificate number 1312077 (see Appendix).

Legionellosis

The HSC Approved Code of Practice, in paragraph 19 states that there is a foreseeable risk of exposure to Legionella bacteria in hot and cold water systems. A system served by the Q-Ton Heat Pump is no exception. The question that is being addressed in this report is whether the Q-Ton Heat Pump and any associated installation works, present any greater or lesser risk compared to other systems and whether such an installation meets the expectation of ALARP (As Low As Reasonably Practicable).

The risk of legionellosis is determined by the following factors, which BS.8580 expects to be considered as part of legionellosis risk assessment:-

Factor	Comment
Contamination	The Q-Ton Heat Pump is a device which exchanges heat from the unit into water. As such it is no physically different in Legionella terms from any other heat source, with respect to contamination. Any contamination of a hot water system comes from the source water, not the hot water generating system.
Amplification	The design, installation, commissioning, condition and operation of the hot water heating system (both the Heat Pump and any associated installation works) can affect the amplification of Legionella.
Transmission	The Q-Ton Heat Pump is a device which exchanges heat from the unit into water. As such it is no physically different in Legionella terms from any other heat source, with respect to transmission. Any transmission of Legionella from of a hot water system comes from the outlets i.e. taps, showers, not the hot water generating system (except possibly during maintenance).
Exposure	The Q-Ton Heat Pump is a device which exchanges heat from the unit into water. As such it is no physically different in Legionella terms from any other heat source, with respect to exposure.
Host susceptibility	The Q-Ton Heat Pump is a device which exchanges heat from the unit into water. As such it is no physically different in Legionella terms from any other heat source, with respect to host susceptibility. However it is recognised that host susceptibility should be considered in this study, in terms of achievement of ALARP.

Summarising the above table, the only factor of relevance to the risk Q-Ton might present relative to other competitor technologies is “amplification”.

4.0 DISCUSSION AND RECOMMENDATIONS

Configuration

A single Q-Ton Heat Pump could be installed with a single hot water storage vessel. Alternatively multiple Q-Ton Heat Pumps and storage vessels could be used. Depending on the application, it may be necessary to specify that multiple units are installed, so as to improve process resilience.

Cold water should be pasteurised before passing into service.

The distribution system pipework features a circulation pump and a diaphragm vessel. In order to avoid any stagnation associated with these items, there should be a single pump with no bypass pipework. A dry spare pump should be held for quick replacement in the event of duty pump failure. The diaphragm vessel should be of the flow-through type and WRAS approved to tolerate the circulation temperature.

Quality of Installation and Commissioning

The reputation of MHIAE will be better protected if the installation of the Q-Ton Heat Pumps is controlled by MHIAE for example through partnerships with contractors which have been trained and audited by MHIAE. If installations are uncontrolled by MHIAE, there is a risk of customer dissatisfaction and reputational damage if a Q-Ton Heat Pump is installed as part of a poor hot water distribution system.

The following hypothetical situation could occur. A Q-Ton Heat Pump installation takes place. However due to a mistake on the part of the contractor, lengths of stagnant pipework are created. An outbreak of legionnaires' disease occurs, which is proven in court to be the fault of the installer, not MHIAE. However by then there would have been several years of adverse publicity by association of MHIAE with the outbreak.

Another potential occurrence could result from poor sizing or commissioning of a Q-Ton Heat Pump, resulting in the customer's expectation for hot water supply not being met. Again, not the fault of MHIAE, but customer perception is likely to be that "a good item of equipment in a poor installation is an inferior item of equipment".

Cautious, Confident Trials

Caution should be exercised in the conduct of trials on customer premises. In discussions, other trial sites have been described. Research and experimentation are worthy exercises, but should be undertaken with care, for example to avoid too many variables and to avoid the potential failure of another novel technology having an impact on the credibility of the Q-Ton Heat Pump.

In particular the following aspects of trials have been briefly discussed:-

Potential Trial Feature	**Potential Consequence**
Retaining the existing hot water generation system on standby	This may result in storage of stagnant water. It might also convey a lack of confidence in the sizing or reliability of the Q-Ton Heat Pump(s).
Operating at low distribution temperatures.	The temperature of hot water distribution is a customer decision. However MHIAE might be wise to avoid installations where the customer is intent on operating below the usual criteria of minimum 60°C in storage and minimum 50°C in circulation. This is particularly important in healthcare environments. Low temperatures, followed by a legionnaires' disease outbreak would result in adverse publicity for Q-Ton Heat Pumps.
Using alternatives to water softening.	Conventional scale control is achieved using ion exchange softening. Alternatives such as chemical or magnet treatments exist, but perhaps should not be selected as part of a retrofit Q-Ton installation. Scale control could fail, which although nothing to do with the Q-Ton Heat Pump, may result in a negative customer impression of the Q-Ton, simply because it coincided with the Heat Pump installation.
Using biocides instead of high temperature.	There are corrosion risks associated with some biocides which would need to be considered before any decision to dose chemicals. However, in healthcare it is not normal practice to

	operate at lower temperatures and installations in such circumstances should perhaps be avoided.

ALARP (As Low As reasonably Practicable) and Susceptibility

The type of hot water system technology which represents ALARP is debatable. In our experience at the Water Hygiene Centre, the following technologies would be considered ALARP:-

Conventional Practice	**Good Practice**	**Best Practice**
ALARP for Water Systems Serving: • General Public.	ALARP for Water Systems Serving: • Healthcare; • Health-compromised; • Elderly.	ALARP for Water Systems Serving: • Specialist Healthcare for Immuno-compromised Patients.
• Calorifier, flow and return distribution system.	• Direct gas fired water heater, flow and return distribution system. • Plate heat exchanger with buffer vessel, flow and return distribution system.	• Electric point-of-use water heater. • Plate heat exchanger, no buffer vessel, electric trace heating of single pipe distribution system.

The following table summarises the position of the Q-Ton in terms of its ALARP status:-

Conventional Practice	**Good Practice**	**Best Practice**
ALARP for Water Systems Serving: • General Public.	ALARP for Water Systems Serving: • Healthcare; • Health-compromised; • Elderly.	ALARP for Water Systems Serving: • Specialist Healthcare for Immuno-compromised Patients.
• Single Q-Ton unit with one or more storage vessels, flow and return distribution system.	• Multiple Q-Ton unit installation, with one or more storage vessels,	• Single Q-Ton unit with one storage vessel, holding water at 90°C or 75°C, single pipe

	flow and return distribution system.	distribution system fitted with electric trace heating.

The Q-Ton could represent ALARP in water systems serving populations of any susceptibility, subject to appropriate design, installation, commissioning, monitoring and maintenance. In the configuration suggested above for the “best practice” standard, the potential energy consequences of operating trace heating to achieve a continuous minimum 55^{o}C in the single pipe distribution system would need to be considered when making any claims regarding the energy performance of the Q-Ton unit. However it should be borne in mind that other centralised hot water generation technology, such as the plate heat exchanger example above would also require energy input to its trace heated pipework.

5.0 CONCLUSIONS

The design and control system of the Q-Ton unit appears to be sufficient to maintain adequately high temperatures in the storage vessel, when supplemented by its daily pasteurisation cycle to raise the whole of its contents to at least 60ºC.

The configuration of the distribution system normally associated with a Q-Ton installation is different from other systems, in that the hot water return does not enter the storage vessel or hot water generator, and therefore it needs careful consideration regarding temperature and flow.

If the distribution system is appropriately designed, with appropriate alarms, then a Q-Ton installation would represent no greater risk than other hot water systems.

The design of the system should depend in the ALARP standard to be achieved, which in turn depends on the population's susceptibility to water borne pathogens such as Legionella.

One feature of the Q-Ton system which could be considered superior to other systems, is the option to store water at 90ºC or 75ºC, which provides an environment which is very adverse for micro-organisms.

It is important for MHIAE not only to control the inherent risk associated with its Q-Ton unit, but also to control and influence the risks associated with its installation, commissioning, monitoring and maintenance.

7.0 REFERENCES

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Mariage, H. Air to Water CO_2 Heat Pump for Commercial Hot Water.

7.0 INTERVIEWEES AND SITE VISIT DATES

Des Franklin – Mitsubishi Heavy Industries Europe Ltd

Herve Mariage - Mitsubishi Heavy Industries Europe Ltd

Hiroyuki Okada - Mitsubishi Heavy Industries Europe Ltd

18/12/12 – Great Fosters Hotel, Surrey

14/03/13 – Great Fosters Hotel, Surrey

Appendix

WRAS®

Water Regulations Advisory Scheme

This certifies that

MITSUBISHI HEAVY INDUSTRIES LTD

has had the undermentioned product examined, tested and found, when correctly installed, to comply with the requirements of the United Kingdom Water Supply (Water Fittings) Regulations/Scottish Water Byelaws.

ESA 30 E HEAT EXCHANGER

This certificate by itself is not evidence of a valid WRAS Approval. Confirmation of the current status of an approval must be obtained from the WRAS Directory (www.wras.co.uk/directory)

The product so mentioned will be listed in the Water Fittings and Materials Directory for a period until:

31 DECEMBER 2018

1312077

Certificate No.

Chairman, Product Approval Group

Secretary

WRAS APPROVED PRODUCT