

Proceedings of the UK Controlled Environment Users' Group

1995 SCIENTIFIC MEETING

“WATER (LIQUID & VAPOUR) IN CONTROLLED ENVIRONMENTS”

Volume 6

Contents

1.	Humidity and Plants. H.G. Jones	2 – 6
2.	Code of Practice for Humidity Measurement. M. Stott	6 - 7
3.	Humidification Systems. M. Witchell	7 - 9
4.	Pure Water Production Systems. J. Cross	10 - 11
5.	Water Hygiene. J. Mellor	12 - 14

**CONTROLLED ENVIRONMENT USERS GROUP
1995 SCIENTIFIC MEETING**

Water (liquid & vapour) in Controlled Environments

The scientific part of the annual meeting consisted of five invited contributions. Summaries of these, supplied by the speakers, follow.

SUMMARIES OF PAPERS

H.G. Jones (Horticulture Research International, Wellesbourne, Warwick CV35 9EF)

Humidity and Plants

This summary of the spoken paper aims firstly to outline the basic principles of humidity and the various definitions that are used in relation to controlled environment studies, and then to outline the main effects of air humidity on plant performance.

1. MEASURES OF HUMIDITY.

There are a wide range of different measures of humidity used in the scientific and technical literature relating to controlled environments and plant responses. It is worth considering the relative values of the different measures used and when each is most appropriate.

1.1 BASIC MEASURES

• ***absolute humidity or vapour density*** (c_w ; x_w)

One of the most widely used measures is the absolute humidity which is the *mass concentration* or *vapour density* and equals the mass of water vapour per unit volume of air (kg m^{-3})

An alternative is to use the ***molar concentration*** (c_w^m), which is the number of moles of water vapour per unit volume of air (mol m^{-3}).

• ***mole fraction or volume fraction*** (x_w)

This is the number of moles of water vapour in a volume of the air as a fraction of the total number of moles in that volume (dimensionless). For a given 'unit' of air changes in temperature, pressure or volume do not affect the x_w , as all components are affected equally. This equals the volume fraction. This type of measure has a real advantage over concentration measures which are very sensitive to changes in temperature or pressure, since these change the volume of the air according to the gas laws. Mole fraction is much more conservative.

• ***partial pressure of water vapour*** (p_w ; e_w)

This is the pressure that is exerted by the water vapour molecules in the air, and is the pressure that the water vapour would exert if allowed to occupy the whole volume (Pa; kPa; mb; mm Hg). Note that the correct SI unit is the Pa.

• ***water potential*** (ψ)

The moisture content of air can also be described in terms of the amount of Gibbs free energy available to do work (J mol^{-1}).

$$\psi = RT \ln(e/e_{\text{sat}}) = RT \ln(\text{relative humidity})$$

- **dewpoint (T_d) or wet bulb temperature (T_w) .**

The dewpoint temperature of a body of air is that temperature at which the water vapour pressure equals the saturation vapour pressure.

The wet bulb temperature is the temperature which a moist surface reaches when it evaporates into an unsaturated atmosphere, as this is dependent on the rate of air movement, standard air movement is usually defined as in an 'Assmann' psychrometer. The relation between e and e_s is given by:

$$e = e_{s(T_w)} - \gamma(T_a - T_w)$$

- **mass fraction (m_w) and mixing ratio (w_w)**

These refer to the ratio of the mass of water vapour in a volume of air to either the total mass or to the mass of air alone. These are widely used in the meteorological literature.

1.2 DERIVED MEASURES

The air humidity is often related to the humidity at saturation - that is the amount of water vapour that air can hold when fully saturated at air temperature. These derived measures include relative humidity and humidity deficit definitions.

- **relative humidity (h)**

When vapour pressure, or absolute humidity or mole fraction, etc. are expressed as a fraction of the corresponding value at saturation, this is termed the relative humidity (dimensionless and expressed as a fraction or as a percentage).

$$h = e/e_{\text{sat}} \text{ OR } c_w/c_{w\text{sat}}$$

- **humidity deficit (δe ; δc_w)**

This is the difference between air humidity and that at saturation. It can be expressed in terms of absolute humidity deficit or vapour pressure deficit (vpd). Note that one commonly refers to the *vapour pressure difference* between a leaf and the air; this is not in general the same as the air vapour pressure deficit because air and leaf temperatures are not the same. One also frequently comes across the use of *vapour pressure gradient* used incorrectly to describe what is correctly termed the vapour pressure difference.

2. COMPARISON OF HUMIDITY MEASURES

For a given volume of air when one changes Pressure, Temperature or Volume, the vapour density, the molar concentration, and the partial pressure all change. On the other hand,

measures such as mole fraction, mass fraction and mixing ratio are all conservative and insensitive to P, T and V under such conditions.

3. HUMIDITY CONVERSIONS

To convert from left column to:

	c_w (g m ⁻³)	e (Pa)	x_w	m_w	w
c_w	1	*T/2.17 or *P/(ρ *0.622)	/ $(\rho$ *0.622)	/ $(\rho$ -0.608*c _w)	/ $(\rho$ -(c _w /0.622))
e		1	/P	*0.622/(P-0.378e)	*0.622/(P - e)
x_w			1	*M _w /M	*0.622/(1-x _w)
m_w				1	/ $(1$ -0.378e/P)

NB. $M_w/M_a = 0.622$ (the ratio of molecular weights of water and air)

T in Kelvin

ρ is density of air (e.g. 1204 g m⁻³ at 293 °)

P is atmospheric pressure (e.g. c. 100,000 Pa)

Saturation vapour pressure of moist air over water is given by:

$$e_{s(T)} = f\{\alpha \exp [(\beta T/(\gamma+T))]\}$$

where

$$\alpha = 611.21$$

$$\beta = 17.502$$

$$\gamma = 240.97$$

$$f = 1.0007 + 3.46 \times 10^{-8} P$$

and T is in °C, and e and P are in Pa.

4. EFFECTS OF AIR HUMIDITY ON PLANTS

The best review of effects of humidity on plants is that by Grange & Hand (1987). It is likely that all the effects of atmospheric humidity on plants can be attributed to effects on transpiration or evaporation in one way or another. Nevertheless, the precise mechanisms operating in any case often counteract each other so that the precise outcome of changing humidity is often difficult to predict.

- **Transpiration and water status**

The primary effect of humidity on transpiration is the direct effect on the driving force for evaporation (through modification of the surface to air humidity difference). The basic equation is

$$E = k \cdot g_1 \cdot (e_1 - e_a)$$

so that increasing air humidity tends to decrease transpiration. The net effect of a change in humidity is, however, rather more complex as ambient humidity also affects stomatal conductance (gl), with decreasing humidity tending to close stomata and hence counteract the increased driving force. The relative magnitude of these two effects can vary, so that in extreme cases transpiration may decrease with increasing humidity deficit (see Jones 1992). Nevertheless the most usual effect is for transpiration to *tend to increase* as humidity decreases, and thus for water deficits to become more prevalent with drier air.

- **Photosynthesis**

Any effects of altered humidity on photosynthesis tend to be indirect, acting either through an effect on stomatal conductance (see above), or through altered evaporation and hence tissue water deficits. For example, decreases in humidity that cause increased water loss can lead to water deficits that may be severe enough to lower net assimilation rates.

- **Growth**

According to Grange and Hand (1987) growth tends to be insensitive to changes in humidity over a wide range (0.2 to 1.0 kPa). There is, however, that growth can be inhibited at both higher humidities and lower humidities.

Very high humidities occur in glasshouses as a result of energy saving measures such as (a) the use of better insulated houses, thus reducing condensation, or (b) reduced air changes (Bakker, 1990; Holder and Cockshull, 1990). On the other hand, very low humidities can also often be inhibitory, both for dry weight, and shoot extension.

How can these contrasting effects be explained? The evidence suggests that where reductions in growth occur as a result of high humidities, the effects only become apparent at very high humidities where the uptake of nutrients in general can be reduced (e.g. Adams, 1980), and especially the translocation of calcium to the leaves is inhibited. Calcium tends to occur at low concentrations in the phloem and the xylem (c. 1 mM), so that where transpiration is low, calcium supply can become limiting. In contrast the reductions in growth that are sometimes found with decreasing humidities, especially in rather dry conditions, probably result either from a tendency for water stress to occur as the rate of water loss increases or from the reduced photosynthesis rate that occurs as stomata close. Although it is often difficult to distinguish these two effects, most of these results are probably due to the stomatal closure effect.

In summary the main effects of humidity on growth are through

- a) water stress
- b) stomatal closure and decreased photosynthesis
- c) altered uptake and transport of calcium and other nutrients.

- **Physiological disorders**

A number of physiological disorders such as blossom end rot in tomatoes, bitter pit in apples and tip burn in lettuce are attributable to poor supply of calcium to the affected organs. Air humidity can have marked effects on the occurrence of these disorders through its effect on transpiration (calcium transport is largely in the transpiration steam).

- **Pests and Diseases**

Many fungal diseases are stimulated by high humidities, and especially by periods when the leaf surface is maintained wet, thus allowing spore germination and infection. Wet leaf surfaces are much more likely to occur as humidities are maintained high. Similarly different pests have differing preferences for humidities. Most interestingly, manipulation of the environmental humidity becomes important when one aims to control pests through the use of fungal insect pathogens such as *Verticillium lecanii*.

5. REFERENCES

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M. Stott (Institute of Measurement and Control, 87 Gower Street, London WC1E 6AA)
Code of Practice for Humidity Measurement.

The National Physical Laboratory (NPL) and the Institute of Measurement & Control (IMC), supported by the National Measurement System Policy Unit (NMSPU), are creating a Code of Practice which will address all aspects of humidity measurement, from the choice of a basic sensor for a routine measurement through to on-line calibration and validation.

The IMC Humidity Panel includes senior representatives from the leading manufactures, suppliers and users in the UK and will collaborate with the full UK industrial humidity measuring community via a questionnaire, surveys and open workshops. A strong international input arises naturally from the current Panel. In addition to the Panel a broad range of industry experts have expressed interest in participating in the project.

A great deal of information exists in the public domain but in most cases it is insufficiently known, poorly expressed, or widely misunderstood. The Code of Practice will bring together such information so that it is:

- readily accessible;
- readily and widely accepted by the humidity measurement community;
- pre-competitive;
- practically applicable;
- a basis against which good practice can be independently assessed, particularly for accreditation of a measurement or calibration service.

The Institute of Measurement and Control will print and publish the Code of Practice and will work with BSI, the ICI and other international bodies to ensure that the Code of Practice is included in future national and international standards considerations.

Anyone working in the field of humidity measurement is invited to participate e.g. by criticising the draft Code of Practice, and should contact the Panel Chairman, Michael Scott via the Institute of Measurement and Control, Tel. 0171 387 4949.

M. Witchell (JS Industrial Services Ltd., Rustington Trading Estate, Artex Avenue, Rustington BN16 3LN) **Humidification Systems**

COLD WATER SYSTEMS

a) UltraMist™: This system is our ULTRASONIC System. It utilises a series of nebulisers that oscillate at an ultrasonic frequency. This causes the water local to the oscillators to cavitate and boil at very low temperatures. The result is a micro-fine "mist". Adiabatic cooling also occurs when this unit is in operation. This system is most suited to low capacity, close control environments. The UltraMist™ system requires good quality water of conductivity less than 100 µS/cm.

b) JetSpray™: This system is our compressed air and pressurised water, atomising nozzle system. The water is atomised at a series of 'nozzles' using the compressed air. There are two principle derivatives of this system - the in-duct and the direct air systems. Adiabatic cooling is a feature of this system.

This system is suited to high capacity applications or large environments requiring humidity control i.e: glass houses.

c) HumEvap™: This is our "evaporative" type of humidifier. It utilises a wetted "honey comb" matrix installed across an airflow. The air is forced through the evaporator. The air is also adiabatically cooled. UV sterilisation on the water circulation side and drainage systems ensure good quality water at all times.

STEAM SYSTEMS

a) Defensor: This is a package steam boiler system, The Defensor utilises 'resistive' heating elements to boil water contained in a stainless steel vessel, the resultant steam is added to an airflow via hose and a stainless steel distribution lance. It is also possible to have a fan unit installed on top of the humidifier in order to "blow" the steam directly into the area to be humidified. Any water quality can be used with this system, with reverse osmosis water offering virtually no maintenance due to lack of scale build up.

- b) Electro-Vap:** This is another packaged type of steam boiler. However it differs from the Defensor system is that it utilises electrical current, passed between electrode plates, to boil the water. The electrodes are housed within a polypropylene boiling cylinder. Again the steam is passed into the airflow via hose and stainless steel distribution lance. The room fan head for 'direct' humidification is also available.
- c) PURE STEAM™:** This is a system which uses an existing steam supply. The pure Steam™ humidifier comprises of a steam separator to remove all the moisture from the steam supply, a modulating control valve and injection lance. Where there is 'spare' steam available already this is the most cost-effective system.

Types of humidifiers and their advantages and disadvantages

Humidifier	Advantages	Disadvantages
Electrode-boiler steam	Cheap to purchase, compact, sterile vapour	Expensive to run (731 W/kg vapour), expensive replacement boilers, non-biodegradable disposable components, require frequent maintenance, expensive to install on site (heavy cables often required), unreliable performance.
Steam injection	Low-cost injector, short evaporation distance, sterile vapour, high capacity, gas-fired, cheaper to run than electric.	Expensive boiler installation, expensive steam pipe runs, amine problem with anti-corrosive chemicals, expensive to run humidifier where heating and humidifier run from same boiler.
Ultrasonic humidifiers	Very low running costs (52 W/kg vapour), simple installation, low maintenance, immediate response to signal, free cooling.	Very expensive to purchase, low unit capacity, demineralised water supply required.
Washer systems, wet-cell humidifiers	Low capital cost, occupy little duct space, free cooling.	Associated with "humidifier fever", recirculate water, cause corrosion, require chemicals and regular cleaning, ineffective at high humidity levels, expensive maintenance.
JS Jetspray™ In-duct humidifer	Low running costs (58 W/kg vapour), low maintenance, hygienic, no chemicals, free cooling, moderate capital cost, quick payback, mains or demineralised water.	Compressed air system required.

J. Cross (Elga Ltd., High Street, Lane End, High Wycombe HP14 3JH) Pure Water Production Systems.

Water used for humidifying controlled environment cabinets must be purified, both to remove hardness salts that would block water jets and to prevent the formation of dust derived from dissolved minerals. The purified water required would typically have a conductivity of 1-50 $\mu\text{S}/\text{cm}$.

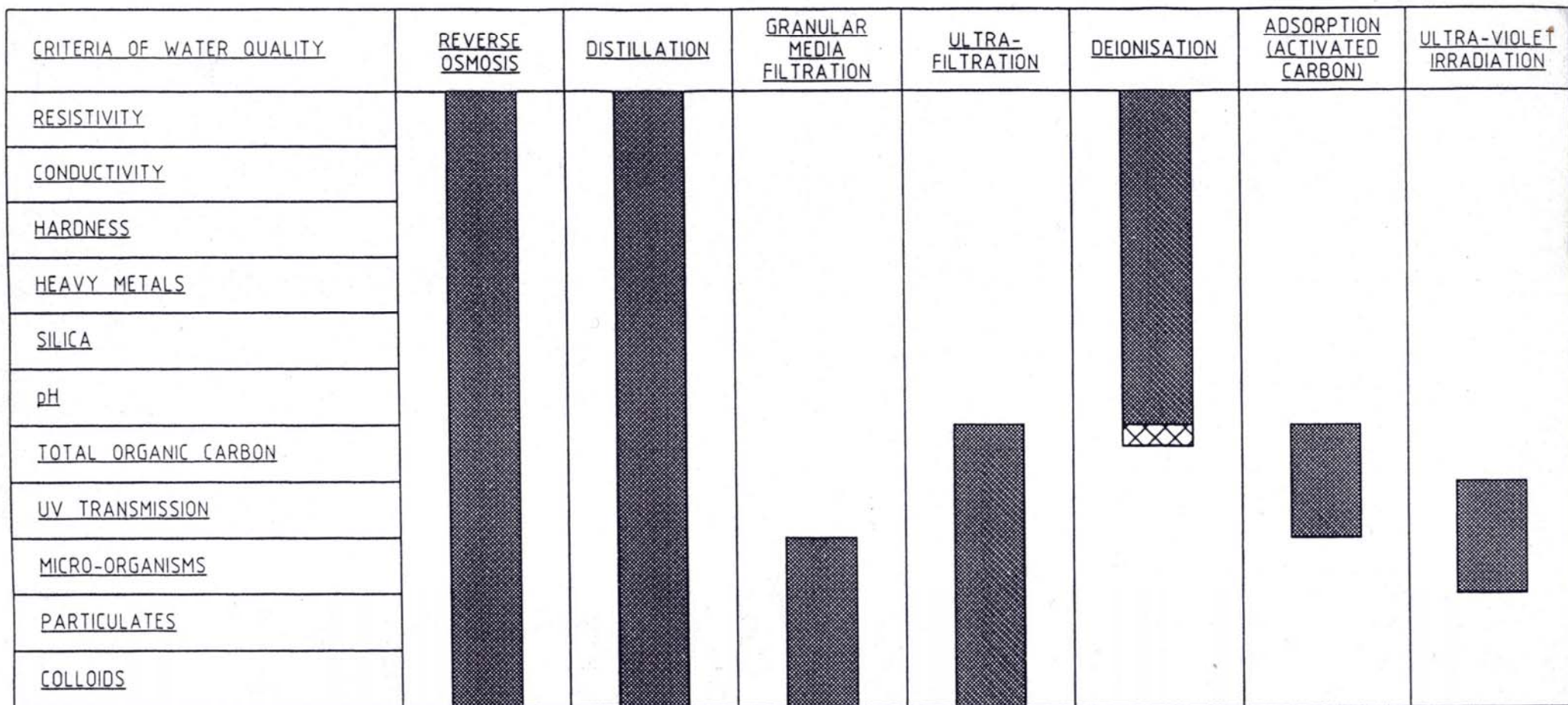
Figure 1 (see next page) shows that distillation, reverse osmosis and deionisation are all water purification techniques that affect the hardness and conductivity of water. But although all three processes can produce water of the requisite quality, reverse osmosis is usually the most convenient and cost-effective technology to use.

Reverse osmosis (RO) is a membrane process that takes place at ambient temperature and does not require aggressive regenerant chemicals. RO membranes typically last for three to five years and are able to remove up to 98% of inorganic salts from the feedwater, together with almost all the non-ionic contaminants. Running costs are minimal and virtually independent of the raw water quality.

Deionisation can also be used to purify water for controlled environment systems, but the running costs of deionisers are directly proportional to the total dissolved solids (TDS) content of the feedwater. So in high-TDS areas, stand-alone deionisers can be expensive to operate. Nevertheless, in some cases inexpensive cartridge deionisers can be a cost-effective alternative to RO units (which have relatively high capital costs) for small controlled environment cabinets.

Distillation requires significant quantities of energy and cooling water and is an environmentally-unfriendly process. The running costs of stills are high and they have low flowrates. Furthermore, in hard water areas stills require an appreciable level of maintenance, resulting in excessive downtime. A detailed analysis of the running costs of a still, together with cost comparisons with other purification systems, is contained in the reprint entitled "Cutting the cost of purified water in the laboratory" (enclosed with these proceedings).

FIGURE 1 CONTRIBUTIONS MADE BY WATER PURIFICATION TECHNOLOGIES TO THE CRITERIA OF WATER QUALITY



J. Mellor (Elga Environmental Ltd.) **Water Hygiene**

1) STATUTORY REGULATIONS

Two statutory regulations refer to water hygiene of domestic supplies within buildings - B.S. 6700 and HS (G) 70. Domestic supply includes both drinking water (which must be fed from direct mains supply rather than via a tank) and all other uses where water can come in contact with the body - especially the nose e.g. showers, flushing toilets and hand basins as well as cooling towers. It also includes hot and cold supplies and the control of bacterial slime and algae growth.

a) B.S. 6700 (issued 1987) - is the British standard specification for DESIGN, INSTALLATION, TESTING AND MAINTENANCE OF SERVICES SUPPLYING WATER FOR DOMESTIC USE WITHIN BUILDINGS AND THEIR CURTILAGES.

A comprehensive document of 100 pages with comprehensive information and recommendations for storage and transfer of water. I use it as a reference document.

Provided its recommendations on installation are followed then its main use with reference to water hygiene is its recommendation to disinfection of an installation. It covers new pipework installations and states that outside pipework into a building should be cleaned and disinfected with 20 mg/L chlorine for 24 h and then flushed clear. This also applies to pipework modifications.

Installations within buildings require an initial flush and clean followed by a 16 h soak in chlorine at a minimum of 30 mg/L.

b) HS(G) 70 (issued 1991) is a Health and Safety Executive guidance document covering THE CONTROL OF LEGIONELLOSIS INCLUDING LEGIONNAIRE'S DISEASE.

It covers the major design criteria involved in both hot and cold water services and air conditioning and industrial cooling systems. It has a section on humidifiers and air washers.

As in B.S. 6700, there are recommendations concerning installation of hardware and on how to minimise the risks of *Legionella pneumophila* within a building. There are specific recommendations on disinfection of water systems.

2) RECOMMENDED TANK AND PIPEWORK DESIGN

All dwellings must have one feed from the mains direct to the kitchen sink. This is obviously intended for drinking use. Any cold drinking water fed from a tank should ideally be at the front of a down line with heavy demand to prevent stagnation and the tank should not impart taste, odour or toxicity to the water.

The most commonly used materials are plastics (A.B.S. and P.V.C.) and fibreglass, copper and stainless steel. Certain fittings are not recommended as they either dissolve gradually and allow toxins out or they can support bacterial or fungal growth. Such materials include lead, leather, some rubbers and some jointing compounds and mastics.

Tanks should not be oversized (HS(G) 70 makes recommendations stagnation) and flow should be in one end and out the other. Where multiple tanks are used water must flow through both tanks. Tanks should have secure covers to prevent ingress of foreign matter. Overflows and vents should be protected by mesh screens. Insulation will almost certainly be required to prevent heat build up in roof locations. Tanks should be easily accessed.

Pipework should be as short and direct as possible with regular usage on all taps. Avoid running cold water pipes adjacent to hot pipes. Ensure the storage tank has a substantial fill and drain off capability to allow rapid chlorinations.

3) REDUCING THE RISK OF *Legionella pneumophila*

The main hazard in domestic water supplies is Legionnaire's Disease and particularly *Legionella pneumophila*. This, together with its sister disease Pontiac Fever, is responsible for some 200 fever cases per year in the U.K. and 1000+ in Europe. The disease exhibits influenza symptoms which developed into pneumonia-type illness. It is fatal in 15 - 20% of cases and especially affects older male smokers.

The following conditions influence the likelihood of *Legionella pneumophila*.

- a) Water temperatures in the range 20 - 50°C and 37°C being the optimum,
- b) Presence of sediment, sludge, scale and organic materials,
- c) Algal slimes and biofilms which *Legionella* can feed on,
- d) Atomised water and droplets allowing water to be breathed in or ingested are thought to be main ways of contacting Legionnaire's Disease.

To minimise risks, system design should avoid water temperatures of between 20 and 55°C and ideally hot water should run at 60°C (but watch for scalding).

Regular (annual) chlorinations should be carried out as recommended in HS (G) 70 to remove slimes and biofilms.

Regular sampling for *Legionella* should be carried out.

4) CLEANING AND SANITISING OF WATER SYSTEMS

Part of the procedures have been covered above. Chlorination using sodium hypochlorite is most usual method although there are some biocides beginning to be used. HS (G) 70 recommends that domestic tanks be inspected annually and if found to be dirty should be cleaned and disinfected.

PROCEDURE

- Physically clean the tank (may mean hosing or scrubbing and even repainting).
- Drain tank down and refill with fresh water. Isolate inlet.
- Add chlorine to appropriate level (50 ppm - 1 h or 20 ppm - 2 h treatment) checking with tablets or colour test.

Pull through down services until sufficient strength of chlorine is detected. Close outlet.

Allow to soak.

Drain off all outlets - neutralise if disposal into waste water systems is required by local water services company. - and refill tank.

Once all outlets have chlorine below 0.2 ppm or mains level recommission.

Take samples.

Also note that reports and chlorination certificates should be kept and health and safety procedures observed.

Notes added by Convenor

1. If humidifiers do not draw down all water to zero on switch off, then when a humidifier is out of service for some time, all residual water should be drained off.
2. Care should be taken if drainage water lies in trays inside installations and equipment.