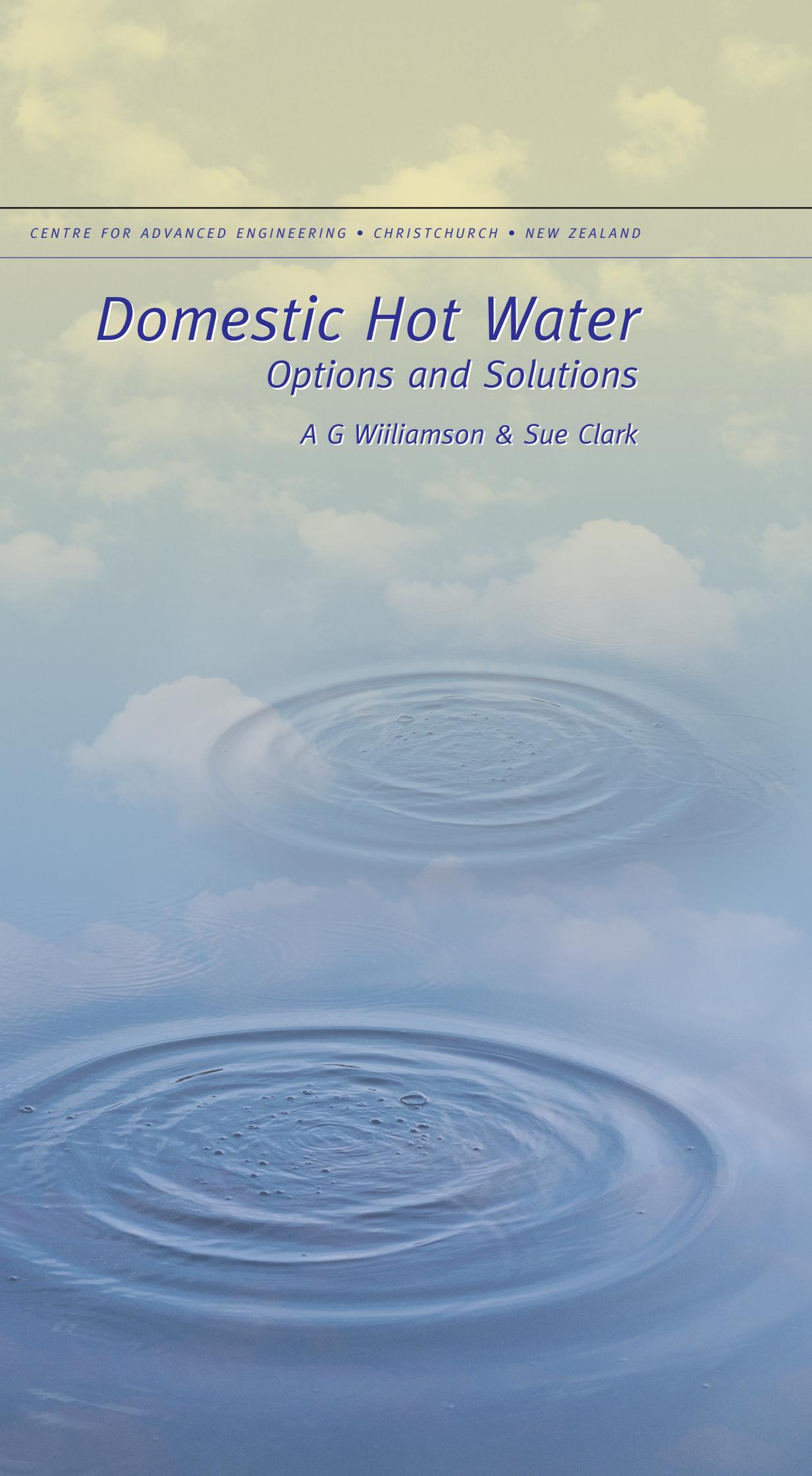
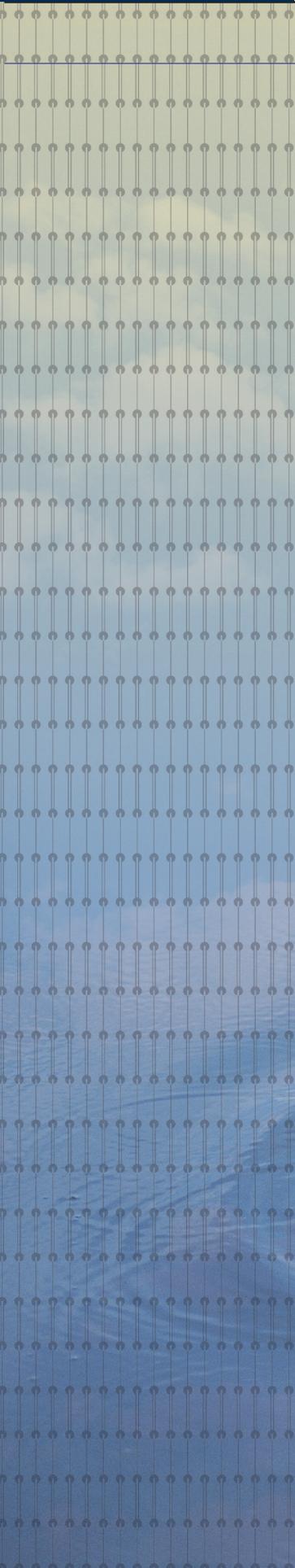




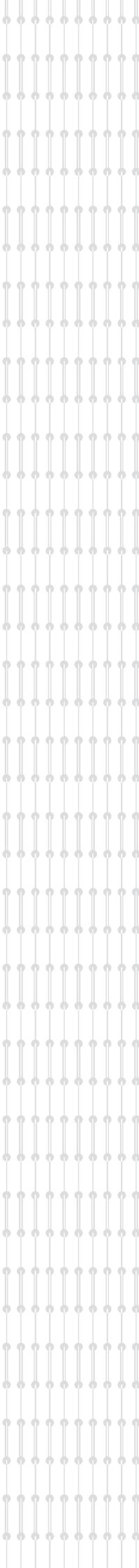
CENTRE FOR ADVANCED ENGINEERING • CHRISTCHURCH • NEW ZEALAND

# *Domestic Hot Water Options and Solutions*

*A G Williamson & Sue Clark*







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*A G Williamson  
Sue Clark*

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# Acknowledgements

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This book has been through several metamorphoses. It started as an incomplete manuscript for a book prepared by Arthur Williamson. This was then developed by Sue Clark and Arthur Williamson into a resource document that was intended to be available as a series of independent but interrelated pamphlets on individual aspects of hot water systems. It has since been reconsolidated into a book by Arthur Williamson.

In the course of these changes the authorship of individual sections has become somewhat confused and I can in all honesty claim no more than editorship of the present volume.

There are many people whose contribution should be acknowledged and some whose input can be recognised by name.

These latter include:

- Mike Reed — BRANZ, formerly of EDA
- James Baynton and Deborah Harding — Baynton and Harding Partnership
- Jacky Lee — energy and building performance consultant

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Brand-named items of equipment are occasionally cited as examples of particular technologies. This should not be taken as an endorsement of that equipment. Nor should it be taken as an implied criticism of other brands not chosen as examples.

In a relatively short book such as this, most items can be readily found from the table of contents. For that reason, there is no detailed index. In some cases figures are repeated to reduce the need for cross referencing.



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# Chapter 1

## *The Importance of Water Heating*

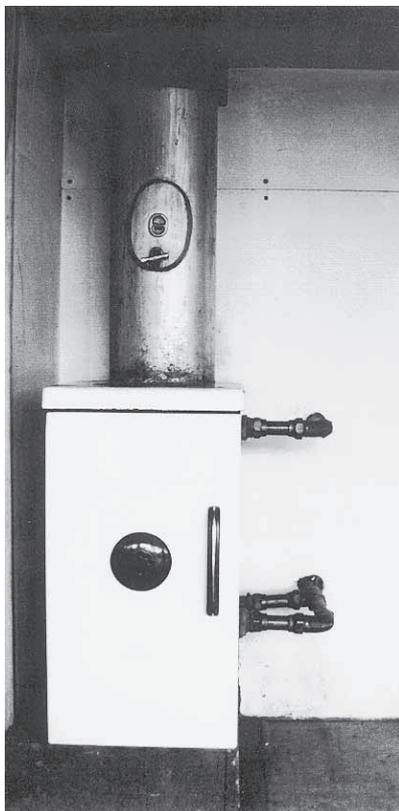
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Hot water plays a major part in modern life. We each use between 40 and 60 litres of hot water per day to wash ourselves, our utensils and our clothes, and the production of hot water represents a significant part of the nation's energy consumption. About 14% of total energy and 35% of all electricity is used domestically and about 40% of domestic energy consumption is used for water heating.

### ***Brief history***

Until the 1930s, and even up to the 1950s in many households, much hot water was produced from solid fuel heating via attachments to solid-fuelled cooking stoves. In addition, so-called chip-heaters produced water for bathing and kitchen use and the traditional fuel-fired "copper" boiler was used for clothes washing.

Even today some water heating is achieved from solid fuel burning in "wetback" attachments to log fires,



**Figure 1: Chip heater**



**Figure 2: Califont (circa 1920)**

especially in areas where space heating is needed for a significant part of the year and log burners are popular.

During the period prior to the 1960s when coal gas was common and piped to most houses, gas-fired "instantaneous" water heaters ("califonts" and "geysers") were common.

The first electric immersion water heaters in New Zealand were developed by Lloyd Mandeno in Tauranga around 1915 and the technology was well established by the 1920s. However, it was not until the intensive promotion by the electricity authorities of electric cookers in the 1930s that household electricity wiring capable of carrying the necessary load was installed

routinely. The convenience and cleanliness of electric water heating relative to solid fuel heating was obvious, and electric water heating became almost universal with hot water available at the turn of a tap.

The power available for water heating in a domestic electricity system has almost always been less than what is needed for instantaneous supply and electric water heating has developed around storage cylinders in which a quantity of water is heated over several hours to bring it to a temperature suitable for use. The modern electric hot water cylinder differs only in detail from the models of the late 1930s, consisting of an inner electrically-heated cylinder and an outer galvanised cylinder with insulation between the two. Thermostats and elements have improved in quality and reliability. Insulation has changed from flock and horse-hair to fibreglass and now to polyurethane foam. The potential load on the distribution system has always been a matter of concern to the power authorities and later to the electricity companies, who have maintained a significant (but diminishing) control over the design, size, installation and management of electric hot water supplies. Even now the supply of electricity for water heating is heavily influenced by the electricity retailing companies with penal rates for uninterruptable supply and special rates (“night rates”) to encourage the use of water heating at times chosen to balance the load on the supply system.

Electric water heating grew rapidly through the 1940s, and by the 1950s electricity had become the dominant method of water heating. With the phasing out of town gas (coal gas) it had become almost exclusive. It was not until the availability of natural gas in the 1970s that gas began to make a comeback as an energy source for both space and water heating. Gas water heaters currently make up less than 10% of domestic installations but their use is increasing, especially in the North Island.

Since the 1960s there have been many developments in the technology of domestic hot water. Whereas earlier systems were almost all low pressure, there is now a wide choice of operating pressures, heating methods and delivery systems, and the number of decisions that need to be made to achieve a safe, effective and energy efficient hot water system that suits the needs of a particular household has increased to the point that it is no longer simply a matter of saying “there shall be a hot water supply”.

Too many houses are still being built with inadequate hot water systems and the deficiencies incorporated during construction usually remain with the house for its life. There are a huge number of households in which the hot water supply is (sometimes woefully) lacking because of inadequate quantities of water,

inadequate and variable flow and/or dangerously high temperatures. In many cases the system uses a great deal more energy than is necessary. For many of these installations relatively simple changes to the existing system can greatly enhance the safety, effectiveness and energy efficiency (and hence the operating costs) of the hot water supply.

One of the purposes of this book is to help house owners, planners, architects, builders and plumbers to take advantage of the wide range of technologies that are now available to produce good hot water supplies in new houses and to enhance the supply in existing houses.

### Energy use in hot water generation

In comparative terms the average household of today uses about a third as much energy heating water as it

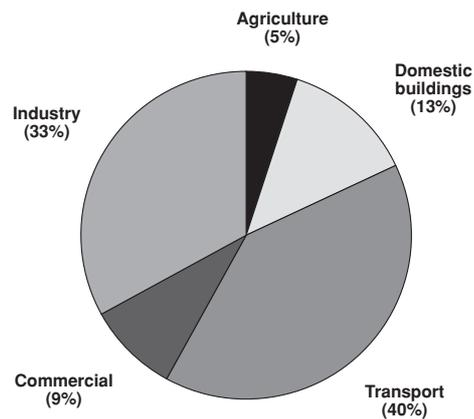


Figure 3: Total energy use vs sector (Source: reference 1)

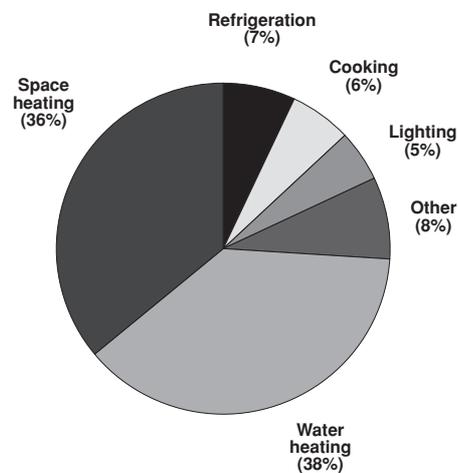


Figure 4: Domestic energy use vs application (Source: reference 2)

does running a motor vehicle. The total energy used by the nation's 1.2 million (approximately) domestic hot water systems is over 4000 GWh/yr.

### The nature of hot water systems

Domestic hot water is used in varying quantities at temperatures from about 37°C for washing delicate fabrics to about 100°C for cooking food and at various temperatures between these limits for washing clothes, dishes and ourselves.

A domestic hot water system must satisfy these requirements safely, efficiently and conveniently. To achieve these ends involves knowledge and understanding of the capabilities of components which make up the hot water system, on the part of designers, builders, plumbers, equipment suppliers and users.

A typical modern hot water supply:

- takes water from a main cold water supply;
- adjusts its pressure to that appropriate to the plumbing layout;
- heats the water by one or several means;
- controls the temperature and energy supply;
- stores (usually) the heated water ready for use;
- establishes the distribution temperature;
- distributes the heated water to various parts of the house; and
- delivers it through a range of flow controls to the

final use, sometimes making a final adjustment to the delivery temperature.

Each of these steps involves a number of technologies and areas of expertise. The complexities and interactions among the aspects of safety, efficiency and effectiveness must be considered together if the performance of domestic hot water systems is to be optimised. Most of the 1.2 million domestic systems at present in use are far from optimum, being wasteful of energy and providing poor service to the user. Some are dangerous.

The deficiencies in hot water systems are mainly:

- inadequate or excessive flow at outlets such as showers;
- inadequate supply (quantity of hot water) for the household's needs;
- dangerously high hot water temperatures;
- interactions between outlets leading to flow and temperature fluctuations in showers; and
- excessive energy consumption.

These defects can be avoided in new constructions by the appropriate sizing of storage cylinders and the use of good insulation, by the appropriate choices of heating methods, appropriate choice of operating pressures and good selection of tapware. However this can affect only the 25,000 or so installations per year in new houses. The complete replacement of the poorly performing hot water systems in the country as buildings are replaced would take about 50 years. Another 35,000 to 45,000 installations per year that receive replacement cylinders can be subject to major upgrade and worthwhile improvements can be made to most of the remaining systems.

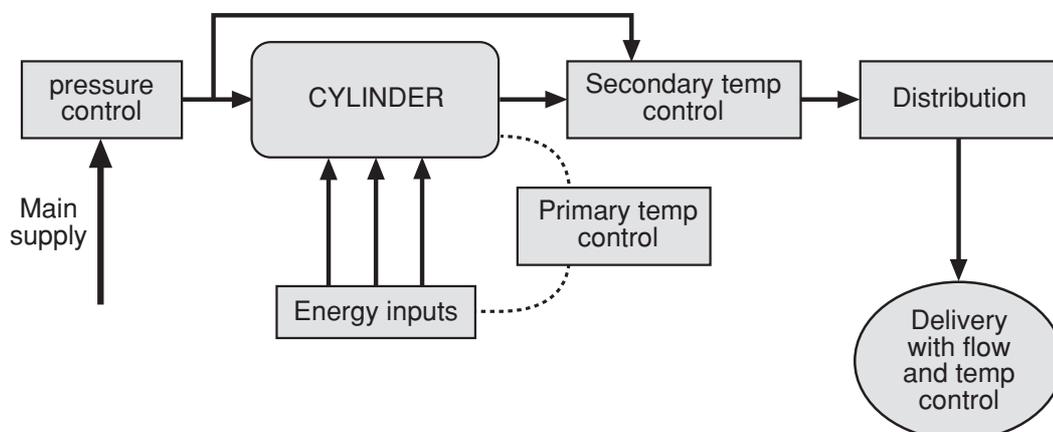


Figure 5: Basic components in a domestic hot water storage system

It is one of the purposes of this book to provide a basis for the appropriate design of hot water systems for new houses.

The other purpose of the book is to indicate ways in which many of the existing systems can be improved to increase safety, provide better service and save both energy and money.

It is often difficult for homeowners to obtain good advice on choosing or specifying a hot water system for their new home. Decisions other than (and sometimes even including) the aesthetics of the tapware are often left to the architect, the builder or the plumber. In some cases there are conflicts between the floorplan of the house and the requirements of a good hot water supply which could have been resolved had they been recognised at an early stage in the planning. Often these can only be coped with at a later stage by arbitrary decisions such as the choice of high water pressure to offset the problems of an unnecessarily complicated pipe-layout or the use of excessively high water storage temperatures to offset the choice of a storage cylinder which is too small for the service required of it.

The upgrading of existing poorly-performing systems is an area more fraught with difficulty. Low hot water flow, inadequate supply, dangerously hot water and interactions between outlets are problems which can sometimes be dealt with at reasonable cost. Sometimes

curing one problem generates another so that compromises must be made. Even when cylinders are replaced, this is often done on a like-for-like basis and the opportunity to improve the system is lost.

This book endeavours to bring together in one place the information and experience needed to provide good initial design and effective upgrades of existing systems with particular reference to New Zealand domestic practice.

Because the many options available in designing or modifying a hot water system interact with each other it is not easy to choose a strictly logical progression through the factors involved. We have chosen in laying out the book to follow the path of the water from the main supply through the heating device along the delivery pipes to the hot water outlet.

While the editors can claim direct expertise in some areas of hot water production, they have had to consult widely and to draw heavily on the knowledge of others who have given their help freely.

#### References

- 1 *EnergyWise Monitoring Quarterly*, No. 13, Oct. 1999, EECA.
- 2 *New and Renewable Energy Opportunities*. 1996, EECA/CAE.

# Chapter 2

## Properties of Water

The physical properties of water which are relevant to hot water supply system performance are outlined below.

### Thermal expansion

The expansion of water on heating is important for two reasons. Firstly it requires that storage cylinders be vented to prevent excess pressure developing, and secondly the venting means that some water must escape from the cylinder during heating.

Water is unusual among liquids in that its density does not decrease smoothly as the temperature rises but passes through a maximum at 4°C. This is shown in Figure 6, Figure 7 and Figure 8.

Of importance to the business of heating water is the fact that there is an expansion between the lowest temperature at which water is supplied to a household supply (about 4 -5°C) and the maximum thermostat temperature (about 80°C) of about 3%.

This in turn means that the volume of water in a 180 litre cylinder can increase by up to 5 litres between cold filling and reaching equilibrium at a temperature of 80°C. In general the expansion will be less than this because the inlet water will be warmer than 4°C and the thermostat setting will be less than 80°C. Furthermore

BC	Density (g/mL)	BC	Density (g/mL)
0	0.99987	15	0.99913
1	0.99993	20	0.99823
2	0.99997	25	0.99707
3	0.99999	30	0.99562
4	1.00000	40	0.99224
5	0.99999	50	0.98807
6	0.99997	60	0.98324
7	0.99993	70	0.97781
8	0.99988	80	0.97183
9	0.99981	90	0.96534
10	0.99973	100	0.95838

Figure 6: Density of water vs temperature

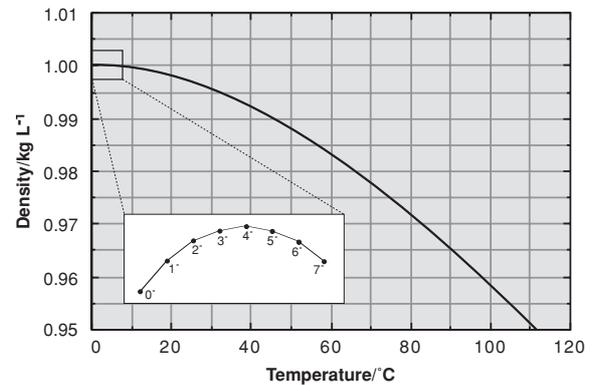


Figure 7: Density of water vs temperature

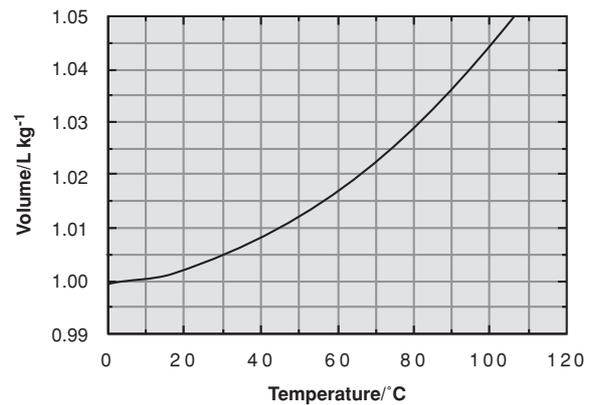
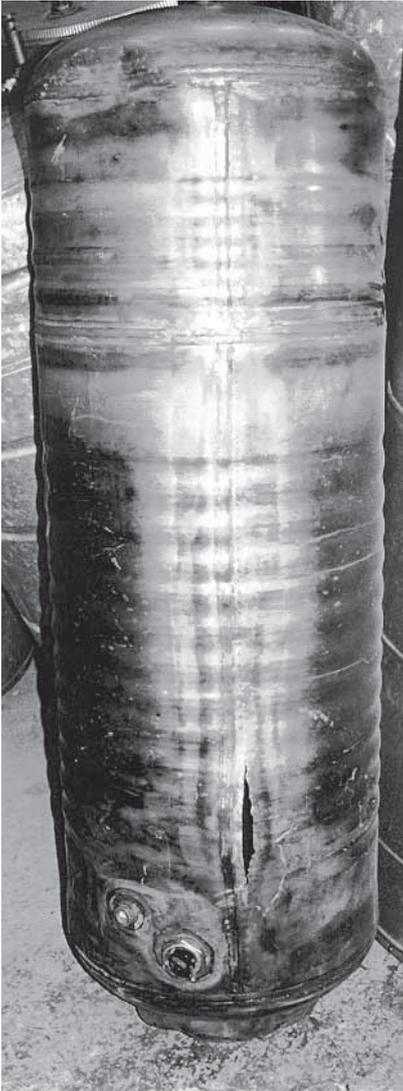


Figure 8: Volume of water vs temperature

the cylinder will usually not be completely “empty” after any one use. Nevertheless there will often be an expansion of about 1-3 percent on heating depending on what fraction of the cylinder is used. Because of the very low compressibility of liquid water this expansion cannot be constrained without developing very high pressures.

The complete restraint of all volume change on heating a volume of water from 15°C to 75°C will result in a pressure of many hundreds of times the pressure of the atmosphere, and such pressures cannot be contained by conventional hot water cylinders. Instead the cylinder will rupture as shown in Figure 9.

To prevent such catastrophic consequences provision must be made for the free expansion of the water on



**Figure 9: Cylinder burst by thermal expansion of water**

heating. This is the reason for the header pipe (exhaust), which is usually fitted to low pressure cylinders. In a header tank system much of the expansion is taken up by movement of the water via the feed line back into the header tank and there is only a slight rise in the overall head in the system.

On the other hand, in systems in which the supply is via a pressure reducing valve, all the expansion takes place in the header pipe and, since this pipe is not usually tall enough or wide enough to take up all the expansion, water will occasionally flow out the top of the header pipe. Because this is hot water from the top of the cylinder it represents a waste, not only of water, but also of energy. In some systems energy waste of up to 3% of the total consumed by the hot water system can occur.

In valve vented systems, the overall safety of the system

is ensured by a pressure relief valve fitted to the top of the cylinder and the regular expansion of the water due to heating is taken up by a “cold water expansion valve” fitted to the bottom of the cylinder and set to release water prior to the operation of the safety valve. This ensures that the normal expansion of water on heating is relieved by the release of cold water from the bottom of the cylinder thus avoiding the wastage of energy.

If a sealed cylinder full of hot water is allowed to cool it is possible for the pressure to fall below atmospheric and the cylinder can partially collapse. A sequence of such events can reduce the volume of storage and even permanently damage the cylinder as shown in Figure 10.

Cylinder collapse can sometimes be initiated by blockage of the header pipe or excessively rapid withdrawal of water.

### ***The heat capacity of water***

The heat capacity is a measure of the energy required to raise the temperature by a specified amount. It determines the amount of energy that is required to produce a given quantity of water at a specified tem-



**Figure 10: Cylinder imploded by pressure reduction**

perature. Unlike the coefficient of expansion, which changes markedly with temperature, the heat capacity of water is very nearly constant in the range encountered in normal domestic water heating practice.

The heat capacity is usually represented as the amount of energy required to heat a given quantity water through one degree C and is usually given as  $4200 \text{ Jkg}^{-1}\text{K}^{-1}$ . Thus it takes 4200 Joules to raise the temperature of 1 kg of water through  $1^\circ\text{C}$ . In talking about water heating, people are accustomed to working in litres of water and kilowatt hours of energy. It is thus useful to know the heat capacity of water in these terms as approximately 860 litre Kelvins per kilowatt hour or 860 litre degrees C per kWh. That is 1 kW for 1 hour will raise the temperature of 860 litres of water by  $1^\circ\text{C}$ . Simple proportionation will yield the energy requirements for other amounts of water and other temperature rises. One needs simply to multiply the volume of water in litres by the temperature rise in degrees C and divide by 860 to get the number of kilowatt hours required. Thus Energy (kWh) = Volume (L) x Temperature ( $^\circ\text{C}$ ) / 860.

For example, to heat 270 litres through  $40^\circ\text{C}$  will require

$$270 \times 40 / 860 = 12.55 \text{ kWh}$$

and this will in turn takes 4.2 hours with a 3 kW element or 6.3 hours with a 2 kW element.

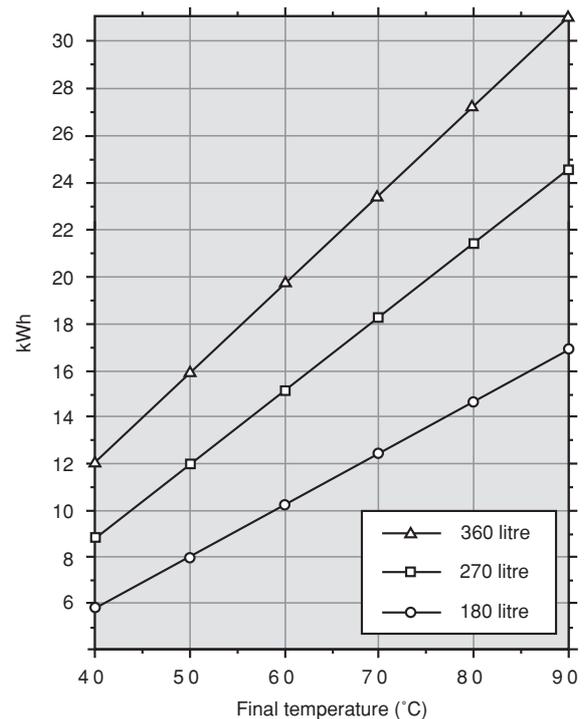
The amounts of energy needed to raise the temperature of typical cylinder volumes from mains water temperature ( $12^\circ\text{C}$ ) to various working temperatures are shown in Figure 11.

## Freezing behaviour

Water is the only common substance which expands on freezing. The volume of a given mass of ice at freezing point is about 9% greater than the volume of the liquid water from which it was formed. When water that is trapped by ice already frozen at both ends of a pipe freezes, this expansion puts very large forces on the pipe. In the case of a steel pipe this will result in rupture of the pipe. Copper pipe will usually stretch and work harden. A copper pipe which has already been stretched by freezing will usually split on subsequent freezing. Even quite small amounts of water can cause dramatic effects as is shown in Figure 12, which shows the result of freezing of about 10 cc of water trapped in a ball valve.

## Evaporation of water

Two factors are important in the evaporation of water.



**Figure 11: Energy required to heat various sized cylinders (initial temperature  $12^\circ\text{C}$ )**

One is the change in vapour pressure of the water with temperature. When the temperature is such that the vapour pressure equals the ambient (atmospheric) pressure, then the water boils, and the temperature cannot rise any further. At sea level (1 atmosphere) water boils at 100 degrees Celsius. If the water is contained in a sealed vessel (e.g. in a boiler) the pressure can rise above atmospheric. The vapour pressure vs temperature curve for water is shown in Figure 13.

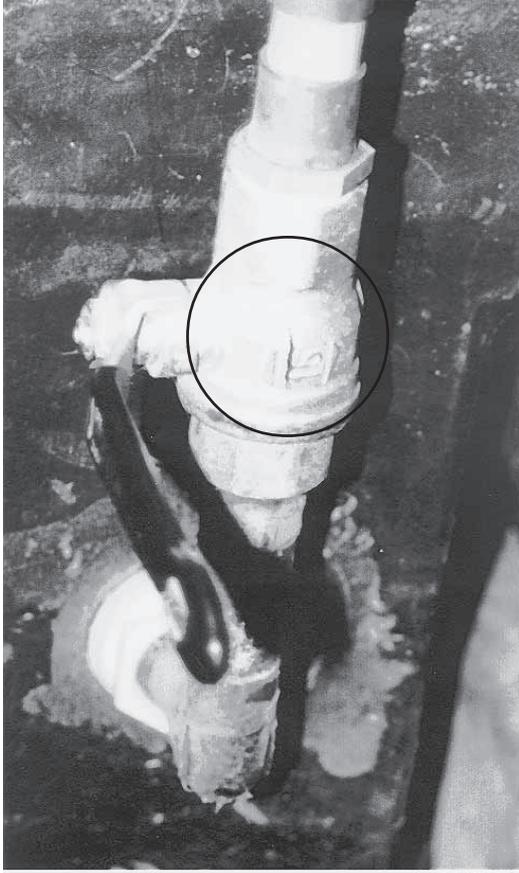
From this it can be seen that very high pressures can be reached at temperatures not far above  $100^\circ\text{C}$ .

The energy required to evaporate a liquid is called the latent heat of vaporisation. This is much larger than that required to raise the temperature of the liquid.

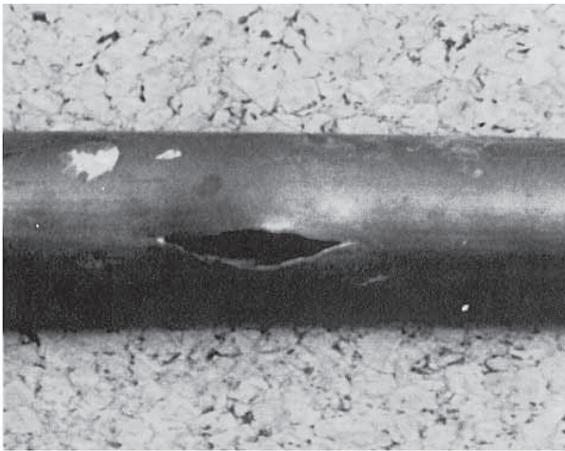
The latent heat of vaporisation is fairly constant over the range of conditions normally encountered in domestic water heating. To heat 1 kg of water from  $10^\circ\text{C}$  to  $100^\circ\text{C}$  requires 380,000 Joules. To evaporate this water to steam at  $100^\circ\text{C}$  requires approximately 2,300,000 Joules, about six times as much as was required to heat the water.

As a consequence of this, large amounts of energy can be accumulated in a cylinder with a vapour space and when the pressure reaches bursting point a violent explosion can occur.

Violent explosions can also occur when a strong stor-



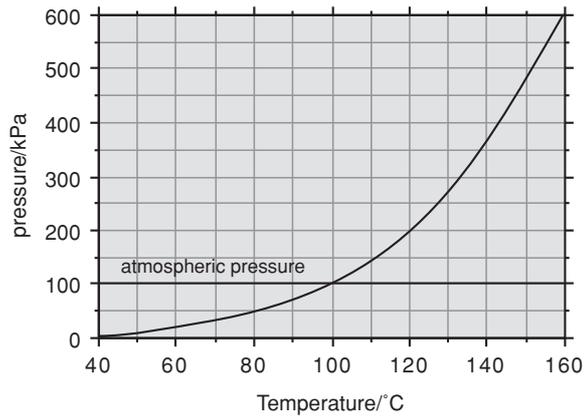
**Figure 12a: Valve body burst by freezing**



**Figure 12b: Pipe burst by freezing**

age cylinder enables water to be raised to temperatures well above 100°C before it bursts. On bursting, the pressure falls and a significant fraction of the water flash vaporises increasing the explosive effect.

Another consequence of the variation of vapour pressure with temperature is that the boiling point of water changes with altitude.

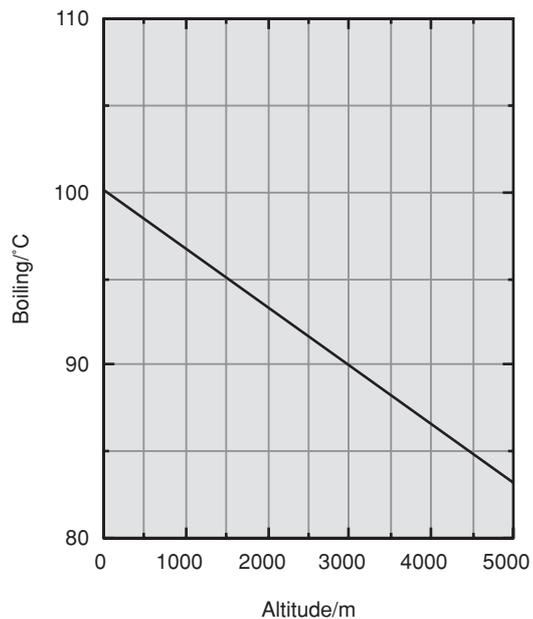


**Figure 13: Vapour pressure vs temperature**

The variation of boiling point with altitude is shown in Figure 14.

This effect is noticeable with boiling water units used for making tea and coffee on demand. These machines are usually set to maintain water at about 97°C.

From Figure 14 it can be seen that at an altitude of 1000 m the boiling point has fallen to about 96.5°C. Since these machines are usually set to maintain water at about 97°C, such a unit taken above 1000 m would boil continuously and to maintain its function of keeping water just below boiling the thermostat would need to be adjusted downward by an amount which can be deduced from the graph. The reduction of boiling point with altitude also explains why one cannot make good tea and why foods take longer to cook in boiling water at high altitudes.



**Figure 14: Boiling point vs altitude**

## Flow of water in pipes

The flow of fluid in a pipe is affected by:

- the diameter of the pipe;
- the length of the pipe;
- the velocity ("speed") of the fluid flow;
- the pressure difference between the beginning and end of the pipe;
- the viscosity ("thickness") of the fluid; and
- the roughness of the inside of the pipe.

## Hydrostatics

### Water Pressure and Head

The pressure in a column of water is dependent on the depth at which it is measured.

The pressure is given by the formula:

$$p = p_f + \rho gh$$

where  $p$  is the pressure,  $\rho$  is the density,  $h$  is the height from the point of measurement to the free surface,  $p_f$  is the pressure at the free surface and  $g$  is the gravitational acceleration. This is the absolute pressure which is relative to an absolute vacuum. In most cases one is concerned with the pressure increase over that at the free surface and  $p_f$  can be ignored. The pressure is then given as:

$$p = \rho gh$$

and is the so-called gauge pressure. This is the pressure which would be read by an "ordinary" pressure gauge referenced to atmospheric pressure (the pressure at the free surface). In plumbing practice pressures are often given simply in terms of the head of water  $h$ . Since the density of water at room temperature ( $997 \text{ kg/m}^3$ ) and the acceleration due to gravity ( $9.805 \text{ ms}^{-2}$ ) are constant, a 1 m head of water corresponds to a pressure of 9775.6 Pa or 9.7756 kPa. A pressure of 1 atmosphere in turn corresponds to 101325 Pa or a head of 10.36 m of water.

This means that atmospheric pressure can maintain a column of water 10.36 m high as shown in Figure 15.

### Syphons

The pressure in a continuous body of water is the same at a given level throughout the body, as shown in Figure 16, irrespective of the shape of the container. In the loop A, all points are below the free surface and the

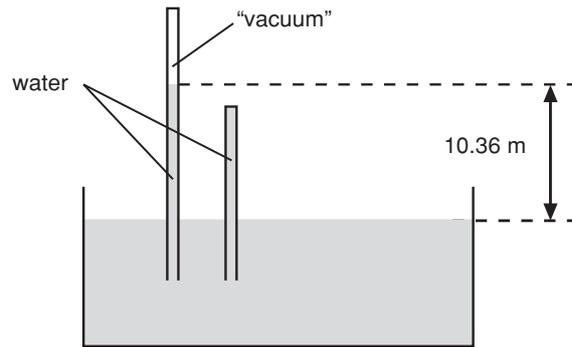


Figure 15: Hydrostatic heads

pipe will fill naturally. In the loop B, the maximum height of the loop is less than 10.36 m above the free surface and the outlet is below the free surface. If the pipe is primed by drawing water over the loop, then water will continue to flow. In the loop C, the height of the top of the loop is greater than 10.36 m and cannot be filled by drawing a vacuum on the outlet.

Atmospheric air pressure is equivalent to 10.36 m of water. Put in another way this means that atmospheric pressure can support a column of water 10.36 m high if there is no other pressure on the upper surface of the water. If the column height is less than 10.36 m, the water can fill a tube and if the tube is in the form of a loop then the water can fill both sides of the loop. The pressure in all parts of the fluid at any given height above an arbitrary datum such as the points  $p$  in Figure 16 is the same. If there is a point in a filled tube forming a syphon that is below the free surface then the pressure is lower than that at the free surface and flow will occur just as it would in a pipe without a rising loop.

The flow will of course only occur if the pipe is full. The filling of an upward loop of pipe is called "priming" and can, in principle, be achieved if the height of

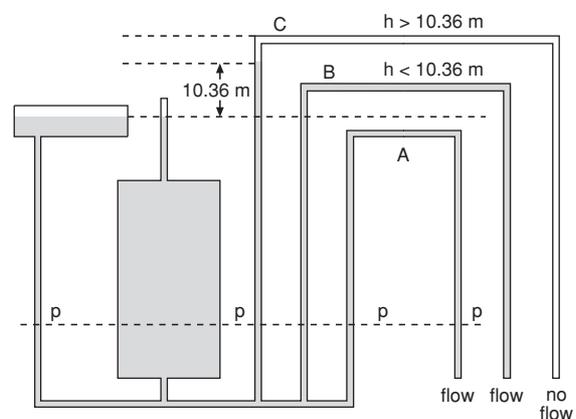


Figure 16: Hydrostatic heads and syphon

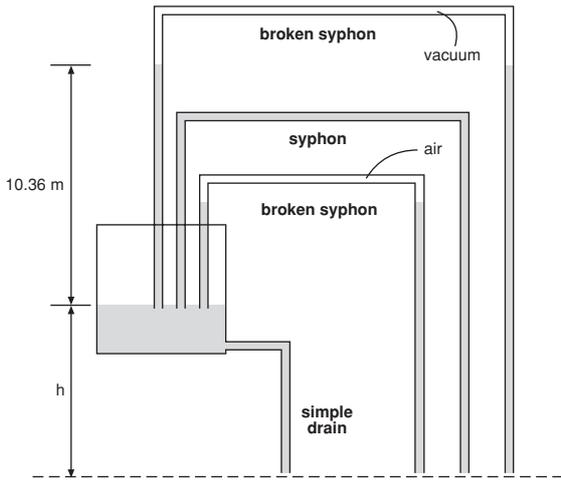


Figure 17: Syphon and broken syphon

the loop above the highest free surface is less than 10.36 m (see Figure 17).

### Thermo syphons

If two columns of water at different temperatures are connected at the bottom as shown in Figure 18, then the pressure at the bottom will be the same for both columns and the heights of the two columns will be given by the relation:

$$h_1 \rho_1 = h_2 \rho_2$$

and the warmer column with lower density will be higher. If a closed loop full of liquid is heated on one side as shown in Figure 19, the pressure at the top of both columns will be the same and the pressure at the bottom of the hotter column will be lower than at the bottom of the cooler column. If the valve at the bottom of the loop is opened there will be a flow from the bottom of the cool limb into the bottom of the hot limb.

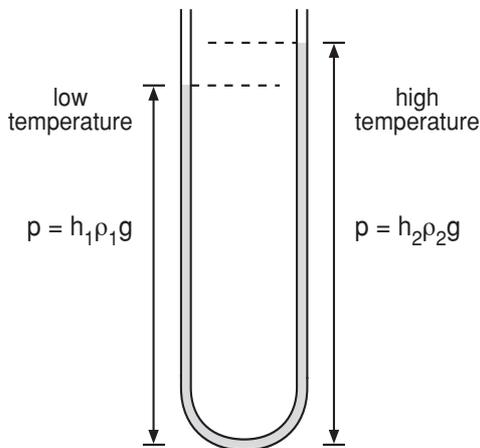


Figure 18: Columns at different temperatures

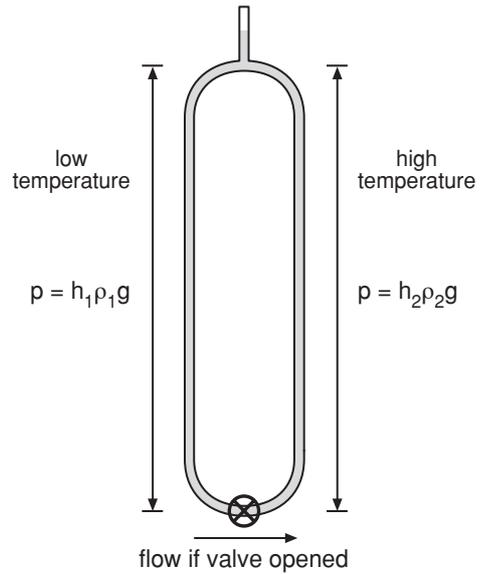


Figure 19: Columns at different temperatures connected at top

This will continue until there are equal quantities of cold and hot water in both limbs.

If the warm side is continually heated and the other side cooled, this will induce a continuous flow round the loop. This is called thermosyphoning. This effect is used to circulate water in wetback collectors and in some solar collectors. The flow in a wetback is illustrated in Figure 20.

In this arrangement all the hot water collects in the cylinder and when the heat source is removed the two pipes leading to the wetback are at the same temperature and the hot water does not back-circulate.

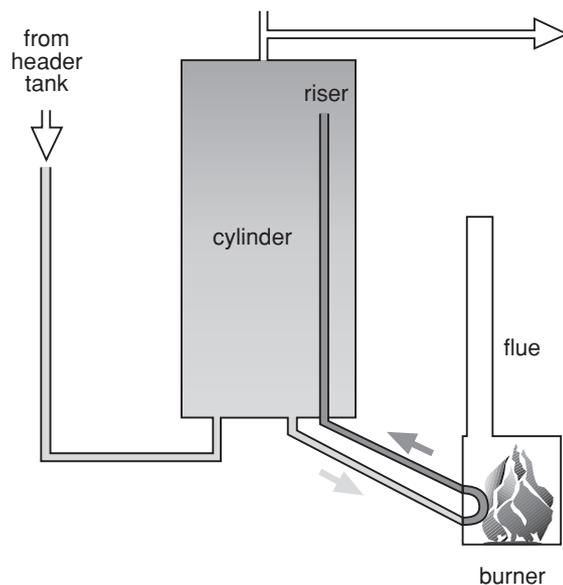


Figure 20: Flow in wetback

## Pressure loss in flow

When fluid flows in a pipe there is a pressure drop in the direction of flow. Conversely, when there is a pressure drop along an open-ended pipe, fluid will flow. The rate of flow depends on the pressure drop, the properties of the fluid, and the dimensions and surface properties of the pipe. At low flow rates the flow is “laminar” and as the velocity in the pipe increases the flow eventually becomes “turbulent”. The pressure drop for turbulent and laminar flow regimes is different.

Since the usual concern in plumbing calculations is with the flow through a pipe with the outlet end open to atmosphere the pressure of interest is usually the gauge pressure

$$p = \rho hg$$

and since one is usually dealing with water at constant  $\rho$  and  $g$  the only variable is  $h$ , so it is convenient to represent the pressure in terms of head of water,  $h$ .

The pressure needed to move a fluid in a pipe is usually represented as the excess height of the fluid that is required to generate the required flow in the given pipe.

## Velocity head

If there were no friction, the head required to generate a given flow would simply be that required to bring the fluid to the required velocity and all one would need to do is start with the volumetric flow,  $V$ , and divide by the area of the pipe,  $a$ .

$$a = \pi r^2$$

to get the velocity

$$v = V/(\pi r^2)$$

One can then calculate the height of fall,  $h$  needed to generate that velocity from the equation

$$mgh = 0.5 m v^2$$

to get  $h = 0.5 v^2/g$

or  $h = 0.5V^2/(\pi^2 r^4g)$

For example if water is required to flow at 1 litre per minute through a 10 mm diameter frictionless pipe then the head required to achieve this is

$$h = 0.5 (1/60,000)^2/(3.142^2 \times 0.005^4 \times 9.76) \text{ m} \\ = 2.3 \text{ mm}$$

and this is called the "velocity head".

Since the velocity increases as the inverse square of the

diameter and the energy goes up as the square of the velocity, then the velocity head for a given volume flow rate will go up as the inverse fourth power of the diameter of the pipe. That is, if the diameter of the pipe is halved then the velocity head goes up 16 fold.

In the case quoted above, reducing the pipe diameter from 1 cm to 0.5 cm increases the velocity head from 2.3 mm to 36.8 mm.

On the other hand the velocity head varies only as the square of the volumetric flow rate for a given pipe diameter.

## Friction head

In addition to the head required to supply the kinetic energy for the fluid motion (in a hypothetical friction-free system), the velocity head, an additional head (pressure) is required to overcome the frictional effects of flow in a pipe. The magnitude of the friction head depends on the velocity of the fluid and its density, the diameter of the pipe, its length and its roughness. It also depends on the viscosity of the fluid. Viscous fluids like treacle tend to have higher friction factors than “thinner” liquids such as water.

Furthermore, there are two characteristic flow patterns called “laminar” and “turbulent”. In laminar flow particular microscopic elements of the fluid tend to maintain their positions in the flow pattern represented by streamlines shown in Figure 21. At a certain point in the flow the characteristic changes to turbulent flow in which mixing occurs across the pipe as depicted in Figure 22. At the transition from laminar to turbulent flow, the friction factor changes quite markedly.

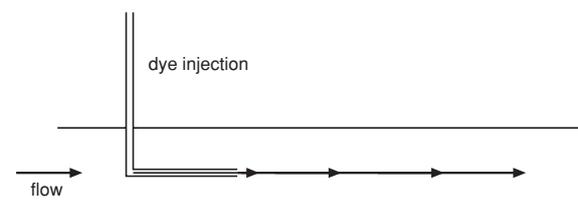


Figure 21: Path of dye injected into laminar flow



Figure 22: Path of dye injected into turbulent flow

The flow regime is determined by a characteristic number known as the Reynolds number,  $N_{Re}$ , which is defined by the relation

$$N_{Re} = DV\rho/\mu$$

where  $D$  = pipe diameter,

$V$  = fluid velocity,

$\rho$  = fluid density, and

$\mu$  = fluid viscosity

The equation may also be written in terms of volume flow rate

$$N_{Re} = 4Q\rho/(\pi D \mu)$$

where  $Q$  = volumetric flow rate

The flow characteristic changes from laminar to turbulent at a Reynolds number of around 2000 and the frictional behaviour of the fluid flow changes accordingly as shown in Figure 23.

The friction head is given by the relation

$$h_f = 4fLV^2/(2gD)$$

where  $g$  is the gravitational constant.

For a typical flow of cold water (10°C) in a 15 mm diameter smooth pipe, the frictional head losses are

shown in Figure 24. Figure 25 shows the corresponding values for hot water (60°C) in 20 mm smooth pipe.

The effects of bends and joins can vary greatly depending on the roughness of the inlet and outlet and the amount of restriction in the bend or joiner. It is not uncommon for these features to be represented as equivalent lengths of straight pipe or equivalent velocity heads.

In addition to these effects, there can be flow restrictions in fittings such as tempering valves and the delivery taps themselves. Most tap and valve manufacturers are able to provide operating characteristics for their products and these should be consulted when specifying the overall hot water system.

As has already been pointed out there can be interactions between the flows in various parts of the system. The degree of interaction is very dependent on the pipe layout and on the flows at the time, and sometimes on the speed of response of temperature control devices such as tempering valves and thermostatic shower valves. While these effects can be more noticeable in lower pressure systems, they are not necessarily confined to such systems. Moreover, even in low pressure systems they can be eliminated by careful design. In particular, in showers the prime requirement is stability and it is advisable to take extra precautions to minimise shower temperature and flow variations. As shown in later sections (e.g. Figure 45, p 31), shower

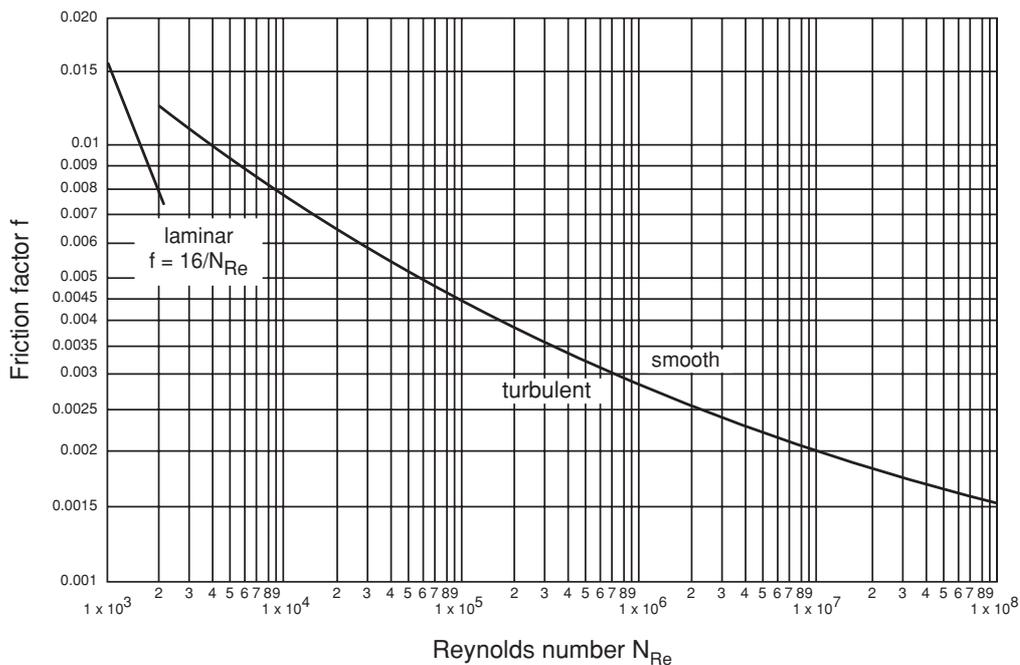


Figure 23: Reynolds number (based on figure from *Chemical Engineers Handbook*, 6th Edition, 1984, p 5-24)

plumbing should be given priority over other uses. The other factor which needs to be considered is the rapid provision of water at handbasins. While the required flow rates for casual handwashing are not great, it is important that hot water be delivered quickly and

attention should be taken to ensure short and well insulated lines to handbasins and kitchen sinks.

Figures 26 to 28 give some recommendations for minimum flows to various outlets and corresponding tempering valve sizes and pipe sizes.

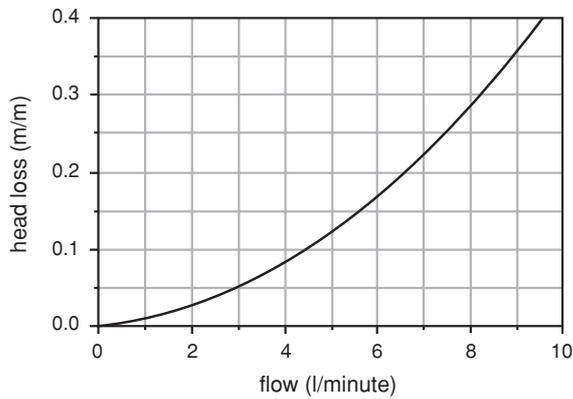


Figure 24: Cold water (15 mm pipe)

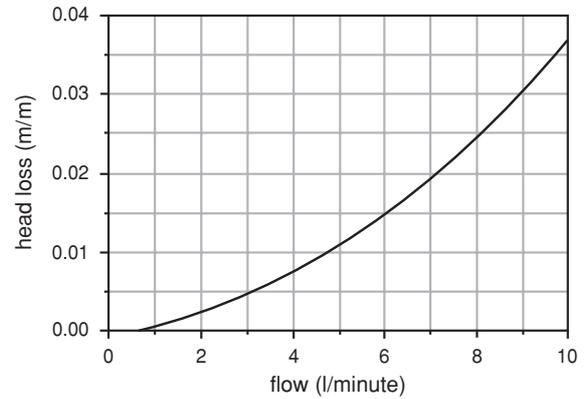


Figure 25: Hot water (20 mm pipe)

Sanitary Fixture	Flow Rate & Temperature (L/m and °C)	How measured
Bath	18 at 45°C	Mixed hot and cold water to achieve 45°C
Sink	12 at 60°C (hot) and 12 (cold)	Flow rates required at both hot and cold taps
Laundry tub	12 at 60°C (hot) and 12 (cold)	Flow rates required at both hot and cold taps
Basin	6 at 45°C	Mixed hot and cold water to achieve 45°C
Shower	6 at 42°C	Mixed hot and cold water to achieve 42°C

Figure 26: Recommended minimum flows to outlets

Pressure of water at valve	kPa	10 - 30	30 - 120	over 120 (high pressure)
	meters head	1 - 3 m	3 - 12 m	over 12 m
Minimum tempering valve size		25 mm	20 mm	15 mm

Figure 27: Recommended tempering valve size

<b>Pressure of water at valve</b>	<b>kPa</b>	<b>10 -30</b>	<b>30 - 120</b>	<b>over 120 (high pressure)</b>
	<b>meters head</b>	<b>1 - 3 m</b>	<b>3 - 12 m</b>	<b>over 12 m</b>
Pipes to tempering valve		25 mm	20 mm	20 mm (15 mm if dedicated <sup>1</sup> )
Pipes to shower		20 mm	20 mm	20 mm (15 mm if dedicated <sup>1</sup> )
Pipes to bath		20 mm	15 mm	15 mm
Pipes to other fixtures		15 mm	15 mm	10 mm

<sup>1</sup> pipe supplies only the shower outlet

**Figure 28: Recommended pipe sizes**

# Chapter 3

## Safety and the NZ Building Code

### High temperatures

Burns are a significant cause of death in New Zealand and a significant fraction of burns are the result of contact with hot water. The effects of severe burns include physical damage and mental trauma, both of which cause much suffering and incur high treatment costs. Many of the injuries from scalding are suffered by children and the elderly. On average in New Zealand, one child dies each year from hot-tap water scalds; two children are hospitalised each week and one child is treated in an emergency department each day.

A full thickness skin scald is also known as a third degree burn.

The severity of a scald depends on both the water temperature and the length of time of exposure. It also depends on the sensitivity of the skin. Small children and the elderly are more susceptible to scalds than are adults.

The range of time/temperature exposure for third degree burns from hot water immersion is shown in Figure 29.

From this it can be seen that for children and the elderly third degree burns are instantaneous at and above 70°C and take only 1 second of exposure for an adult. At 60°C a child would receive a third degree burn in 1 second and an adult in 5 seconds. When the temperature is reduced to 55°C the relevant times are 10 seconds for a child and 30 seconds for an adult.

Given that the very young and the elderly do not generally react as quickly as adults, their risk of scalding by hot water is very high at temperatures much above 55°C\*.

In terms of comfort, the human body is relatively intolerant of temperature change. For example, typical showering temperatures range from cool at 38°C to hot at 44°C. In view of this, delivery temperatures above 45°C at fixtures used for washing would seem to be adequate. On the other hand it is perceived by many that higher temperatures are desirable for dishwashing and “hot” clothes washing and this is reflected in the development of distribution systems, discussed later, in which water at different temperatures is delivered to different parts of the house.

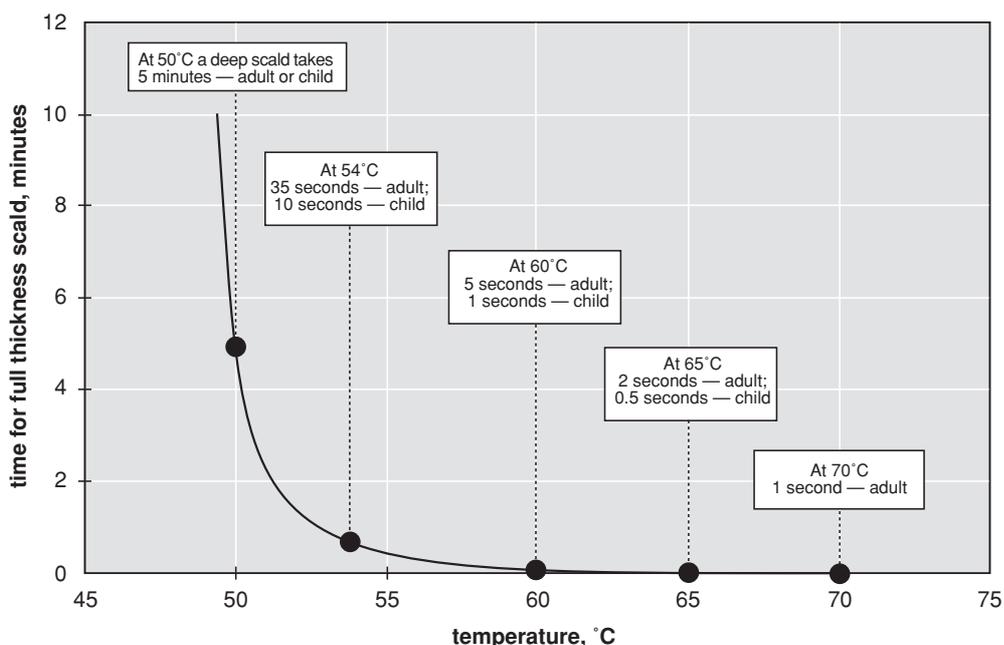


Figure 29: Burn times for third degree burns (reference 1)

\* A 1994 survey by Tauranga Electricity Limited of 320 hot water installations showed that 45% had water storage temperatures above 65°C.

## Low temperatures

The bacteria which cause Legionnaires' disease (*Legionella pneumophila* and other legionellaceae) are known to exist in domestic hot water systems<sup>2</sup>. Although infection is believed to require inhalation of contaminated water droplets and is most common with airborne mist from air conditioning systems and cooling towers, there is some concern that this can also occur in domestic circumstances, especially in showers. Estimates quoted in various sources for cases of Legionnaires' disease traceable to domestic hot water systems range from none to a few in the whole Western World. On the other hand, some authorities claim that deaths previously attributed to pneumonia may in fact have been the result of legionella.

*Legionella* are believed to multiply well in the range 25°C to 40°C to be static above about 45°C and to be killed in a very short time above 60°C.

For the reasons outlined here and in the previous section, the New Zealand Building Code currently requires that hot water storage systems be equipped with thermostats capable of being set to 60°C or higher and that water be delivered to personal ablutions facilities below 55°C (or below 45°C in the case of old peoples' homes, childrens' centres and housing for intellectually and physically disabled.) These conditions can be met with the aid of tempering valves.

## Bursting of hot water cylinders

There are two possible modes of bursting failure. One is simple splitting of the cylinder under hydraulic pressure, which has already been discussed. The other is explosive rupture. The risk of explosion is relatively small as the conditions required to create an explosion are very special.

A completely sealed cylinder full of water will experience a large pressure increase as the water is heated and its natural tendency to expand is restricted. In an open vented system this pressure is relieved by expansion in the header pipe. In a valve vented system the pressure relief valve or cold water expansion valve will relieve the pressure by venting a small quantity of water to waste. If the expansion is prevented the pressure will rise rapidly and the cylinder will burst while the water temperature is still well below the boiling point. This does not involve any significant amount of energy and the bursting of the cylinder will not take place explosively.

## Explosions

On the other hand a mains pressure cylinder is made of

much stronger material (5 mm steel) than is a low pressure (copper) cylinder and is therefore able to withstand a higher internal pressure before bursting. However, even in these cylinders, it is necessary for the pressure/temperature relief valve(s) to jam or block AND for the thermostat to become fixed in the "on" position before a potentially explosive situation can develop. In this case it may be possible to raise the temperature of the water to well above 100°C before the bursting pressure is reached and in such a case the bursting of the cylinder is accompanied by an explosive vaporisation of the now superheated water.

That this form of failure is not limited to mains pressure cylinders is illustrated by Figure 30, which shows the results of the explosion of a simple underbench hot water cylinder, the outlet from which had been incorrectly modified.



**Figure 30: Explosion of underbench cylinder**  
(Source: reference 3)

The New Zealand Building Code (clause G12) now requires that all new valve-vented systems be fitted with energy cut-out, expansion control valves, and pressure relief valves. Older mains pressure systems that do not incorporate energy cut-outs, in areas with poor water quality, are at added risk.

## The New Zealand Building Code

The New Zealand Building Code aims to protect the health and safety of New Zealanders. All requirements of the code are *minimum* legal standards. This includes *minimum* energy efficiency standards. The code should **not** be regarded as describing *good trade practice*. Good practice will often significantly exceed the requirements of the Building Code.

The Building Code falls within the Building Act 1991, which aims to create uniform legal requirements for buildings throughout the country. Wherever possible the Code is *performance based* rather than *prescriptive*. That is the Code describes the performance that must be achieved rather than the manner in which it shall be achieved. Nevertheless it also includes “acceptable solutions” which are descriptions of methods that will be deemed to satisfy the performance requirement.

The Building Code covers all new buildings and alterations to existing buildings (whether a building consent is required or not). Under section 38 of the Act, alteration work must continue to comply with the provisions of the Code “*to at least the same extent as before the alteration*” For simple replacements, for example the replacement of most hot water cylinders, a consent is not necessary if the replacement is “like for like”.

### Performance requirements for water heaters

The building code regards storage water heaters as building elements rather than as appliances.

The following are abridged extracts from the performance requirements of the New Zealand Building Code relating to water heating. With each requirement is our interpretation (in italics) of the intended meaning of the requirement.

#### Clause B1: Structure

##### Performance

B1.3.1 *Building elements* shall have low probability of rupturing, becoming unstable, losing equilibrium or collapsing during *construction or alteration* and throughout their lives.

*Not to structurally fail during normal processes of installation, maintenance, system alteration and service use during their life.*

B1.3.2 *Building elements* shall have low probability of causing loss of amenity through deformations, vibratory response, degradation or other physical characteristics throughout their lives, or during construction or alteration when the building is in use.

*Be reliable and functional during their life. Not to degrade or deform prematurely relative to their specified intended life. (B2.3)*

B1.3.3 Account shall be taken of all physical conditions likely to affect the stability of *building elements*.

*Conditions such as heat, cold, moisture, wind and earthquakes must be considered for both installation and the construction of the unit.*

## Clause B2: Durability

### Performance

B2.3 From the time a code *compliance certificate* is issued, *building elements* shall with only normal maintenance continue to satisfy the performances of this code for the lesser of; the *specified intended life* of the *building*, if any, or...

*The manufacturer must declare the intended life of the unit by way of specifying where it can be installed. NZ manufacturers claim they satisfy B2.3 (d) 5 years (Note also Consumer legislation)*

- (b) For services to which access is difficult: the life of the *building* being not less than 50 years.
- (c) For other building elements having moderate ease of access but which are difficult to replace: 15 years.
- (d) For *building elements* to which there is ready access: 5 years.

## Clause G9: Electricity

### Performance

G9.3.1 The electrical installation shall incorporate systems to:

Protect people from contact with parts of the installation which are live during normal operation, and to prevent parts of the installation or other building elements becoming live during fault conditions.

Protect *building elements* from risk of ignition, impairment of their physical or mechanical properties, or function, due to temperature increases resulting from heat transfer or electric arc.

*Protect people from electric shock, and buildings from the risk of fire. (Note also the Electricity Regulations)*

## Clause G 12: Water Supplies

G12.3.4 Where hot water is provided to *sanitary fixtures* and *sanitary appliances* used for personal hygiene, it shall be delivered at a temperature which avoids the likelihood of scalding.

*Control of the water temperature such that it is delivered at a safe temperature at the outlets to certain fixtures and appliances where there is a risk of injury. This control is not usually part of the water heater (installation issue) but needs to be considered at the product development stage. It is relevant to storage heaters as technologies develop. An acceptable solution to meet the requirement is the installation of tempering valves to pipework which feeds personal hygiene outlets.*

G12.3.5 Water supply systems shall be installed in a manner which:

(a) avoids the likelihood of potable water contamination within both the system and the *water main*.

*The water heater must not contaminate the hot water supply. This relates to all the materials used that are in contact with the water. It also relates to the back-flow of water from the storage vessel. This is usually an installation issue.*

(b) Provide water to *sanitary fixtures* and *sanitary appliances* at flow rates which are *adequate* for the correct functioning of those *fixtures* and *appliances* under normal conditions.

*The water heater must be designed to provide adequate flow rates for use. This requirement means that the inlet and outlet sizes (and design) must be related to the in-service operating pressures and flows.*

(c) Avoids the likelihood of leakage.

*The water heater must be designed and constructed such that leakage during its life is unlikely. This covers all aspects of materials, manufacture, installation and maintenance.*

(d) Allows reasonable access for maintenance of mechanical components.

*This mainly applies to installation, but it does mean access to serviceable components within the water heater must be provided.*

G12.3.6 Vessels for producing or storing hot water shall be provided with safety devices which:

(a) relieve excess pressure during both normal and abnormal conditions, and,

*The maximum working pressure must be stated along with the method of satisfying the requirement. This may mean providing installation instructions and/or fittings and connections for an open vent pipe or pressure relief valve.*

(b) Limit temperature to avoid the likelihood of flash steam production in the event of rupture.

*The requirement for safety devices to prevent the water temperature from exceeding 100°C. Typically this means providing for the fitting of a temperature and pressure relief valve, thermostat and energy cut out.*

G12.3.7 Storage water heaters shall be capable of being controlled to produce, at the outlet of the storage water heater, an adequate daily water temperature to prevent the growth of legionella bacteria.

*The water temperature control and heating unit must be reliable and capable of raising the stored water temperature to over 60°C on a daily basis. This is mainly to kill Legionella bacteria.*

## Clause H1 Energy Efficiency

H1.3.3 Systems for the heating, storage and distribution of hot water to sanitary fixtures or appliances shall:

(a) be constructed to limit heat losses from storage vessels and distribution systems, and

*The water heater must be designed and constructed to reduce heat loss. This means thermal insulation as well as any other design features that will reduce heat loss.*

(b) limit the energy lost in the heating process having regard to the energy source used.

*The energy transfer to the hot water process must be efficient. This requirement mainly relates to fuels such as gas, oil and solid fuel.*

The construction, installation and quality of insulation of hot water cylinders are covered in New Zealand Standards<sup>4</sup>.

## References and Notes

- 1 Moritz and Henriques. *Am. J. of Pathology*, 1947 23:695-720.

- 2 *Water Efficiency: A Resource for Utility Managers, Community Planners and other Decision Makers*. Section 16, Rocky Mountain Institute, 1994.
- 3 Photo courtesy “*The Press*”, Christchurch.
- 4 NZS4607:1989 *Installation of Thermal Storage Electric Water Heaters: Valve Vented Systems*
- 5 NZS4608:1992 *Control Valves for Hot Water Systems*.
- 6 NZS6214:1988 *Thermostatic and Thermal Cut-outs for domestic Thermal Storage Water Heating*.
- 5 New Zealand Building Code G12.
- 6 AS/NZS 3500.4.2:1997. Hot water supply systems — acceptable solution.

Other New Zealand standards relating to domestic hot water systems

NZS 4305: 1996	Energy efficiency Domestic type hot water systems
NZS 4602:1988	Low Pressure Copper Thermal Storage Electric Water Heaters
NZS 4603 1985	Installation of low pressure thermal storage electric water heaters with copper cylinders (open vented)
NZS 4606 :1989	Storage water heaters
NZS 4613: 1986	Domestic solar water heaters
NZS 4614:1986	Installation of domestic solar water heaters
NZS 4617: 1989	Tempering (three port mixing) valves
NZS 6205: 1982	Energy labeling of household appliances Part 2 The energy labeling of thermal storage electric water heaters

New Zealand standards relating to electrical safety

NZS3350 2.21:1999
NZS3350 2.35:1999



# Chapter 4

## Water Use — Quantity and Quality

In order to fully specify a hot water supply system one needs to know both the rates of flow and the amounts of hot water used at various times of the day. In both of these respects the variation among households is very wide and it is difficult to define an “average” or “typical” household.

In many cases there is a wide discrepancy between the current use and potential use. For example, one may be dealing with a four bedroom dwelling capable of housing six people, but presently occupied by only two. How does one decide on the appropriate size of storage cylinder for the house? How does one compare the hot water storage needs of a household with four people, three of whom are at home most of the day (e.g. parent and two small children), with that of a household with four adults all of whom shower within a short period each morning, who are out of the house all day and who do their washing and shower again at night? How does one design for a household in which all the daily hot water requirement is heated over a few hours in the night (night rate) and used throughout the day?

Moreover, the amounts of hot water used and stored are changing in response to changes in habits (e.g. more showers) and technology (e.g. cold water detergents, instantaneous heaters and appliances which heat their own water). The information given here attempts to provide a basis on which a designer can estimate usage, and later sections indicate ways in which flexibility can be achieved. However, it should be kept in mind that these figures can be no more than a guide and specific cases can be very different from the average.

Over the past few decades a number of changes have taken place in the use of hot water in New Zealand households.

The quantity of hot water used by a “typical” household at various times of the day is changing and will continue to change with social and technical developments such as the average number of people per household and the types of equipment used in the house.

Because the house is likely to have a life well in excess of fifty years and because the occupancy and lifestyle of the occupants are likely to change during that time, it is important to try to design hot water systems to be flexible enough to accommodate these changes.

Even today, a large number of houses have insufficient hot water. Many older houses have a mere 135 litres (30 gallons), which is now deemed adequate for a two-person household. The distribution of cylinder sizes is shown in Figure 31, based on the BRANZ house condition survey<sup>1</sup>.

Size ▼	Type ►	Electric (%)	Gas (%)
135 L		34	13
135 - 180 L		3	44
180 L		51	28
180 - 270 L		1	13
270 L		8	
> 270 L		4	2
more than one cylinder		7	2

**Figure 31: Distribution of storage cylinder capacities**

The ratio of electric/gas storage systems in the sample was 4:3. In this survey, about one-third of all houses were considered to need 270 litres or more, whereas only 13% actually had such capacity.

### Showers and baths

The greatest domestic use of hot water is for showering and/or bathing. A bath uses between 40 and 100 litres of water from the water heater. In general, a bath is believed to use more hot water than a shower. However this depends on the flow in the shower and the length of time of the shower, both of which can vary greatly. Low flow showers can deliver as little as 5 litres per minute while multiple nozzle high flow showers can use in excess of 24 litres per minute. There is probably an even greater variation in shower times from as little as two minutes to as much as twenty minutes or even more.

Most New Zealand homes have low pressure hot water systems operating at heads of 3 - 7 m. The shower flow in such systems is usually between 5 and 10 litres per minute and is very dependent on the design of the shower head. It is also often susceptible to the pressure fluctuations that can arise from opening of other taps on the same line as the shower. Although it is possible

Shower Flow litres/minute	Time in Minutes						
	7	10	20	30	40	50	60
6	25	36	72	108	144	180	216
8	33	48	96	144	192	240	288
12	50	72	144	216	280	360	432
16	67	96	192	283	384	480	476
18	76	108	216	324	432	540	648
20	84	120	240	360	480	600	720

Figure 31: Volumes of hot water (litres) drawn from water heater

to design a low pressure system which gives good shower flows independent of other taps in the house, this is frequently not the case. One palliative for these problems is to raise the operating pressure of the system and many plumbing system designers and specifiers now go to the other extreme of using high pressure hot water systems (often called mains pressure).

While this usually eliminates the inconvenience of low water flow, it often introduces the other problem of excessive water flow and waste of both water and energy. Raising the water pressure usually (but not always) reduces the possibility of flow and temperature fluctuations in showers resulting from turning other taps on and off.

Figure 31 lists the amount of hot water (at 60°C) which is drawn from a water heater for showers at various flow rates and shower times. It runs up to a total time of 1 hour to allow for consecutive showers by several people. It is based on a cylinder delivery temperature of

60°C, a shower temperature of 40°C, and a cold water temperature of 10°C. The availability of shower water can be scaled linearly for other cylinder sizes.

The lightly shaded figures show the likely volume for an ‘average’ shower and the heavily shaded figures show when the capacity of a 180 litre cylinder is exceeded.

This figure demonstrates the importance of appropriate sizing of a storage water heating system. The other factor in providing an effective water supply is the recovery time. This is shown in Figure 32.

### Spa baths

Spa baths are increasing in popularity and can be major users of hot water. In some households the introduction of a spa bath has imposed an intolerable load on the existing hot water supply. The spa bath should be treated as a special case and needs to be specifically designed and provided for.

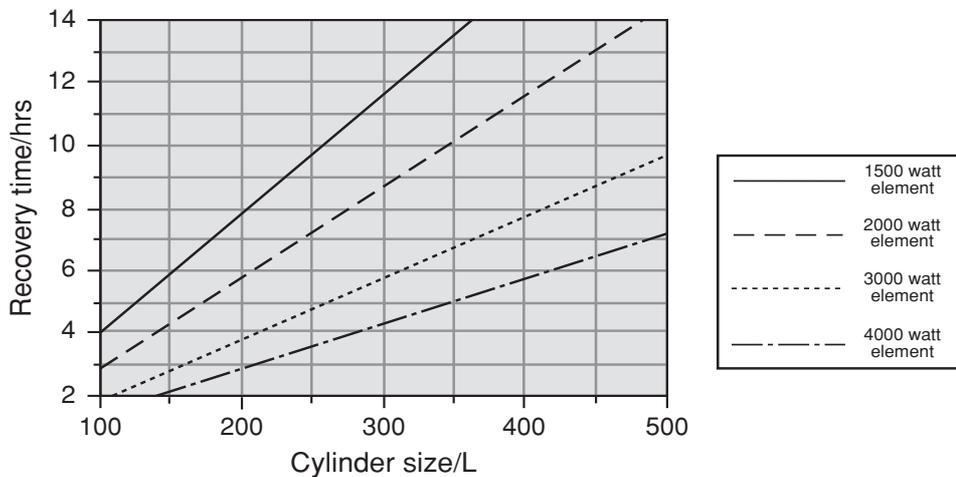


Figure 32: Recovery times for hot water cylinders

## Clothes washing

Machine washing of clothes uses between 50 and 100 litres of hot water per wash and can be a major consumer of hot water. On the other hand many households now use cold water detergents and cold water washing (20°C is advised by most washing machine manufacturers).

Some washing machine manufacturers specify a regular hot wash to clear the machine of accumulated detergent residues, so many households using cold water washing will still do an occasional hot wash.

## Utensil washing

Dishwashers use between 20 and 40 litres of water per wash. However, many dishwashers have an optional cycle which uses a cold water supply and heats the water within the machine. Some are dedicated to such a cycle and are plumbed only to the cold water supply.

Washing dishes by hand uses about the same amount of water as a dishwasher.

## General use

Hand washing, kitchen use (other than for dish washing) and other general hot water use accounts for 10 to 20 litres per day. This use can be considerably increased by an inappropriate plumbing layout involv-

ing, for example, long pipe runs to points of minor use. This aspect of water use is addressed in a later section.

The examples shown in Figure 33 illustrate the range of hot water demand that can result from varying family habits. The table shows the quantities of hot water, supplied at 60°C, needed to satisfy two different patterns of behaviour.

## Estimating domestic hot water demand

This can be estimated from the expected use of all the hot water appliances in the house or from a “rule of thumb”. The former is likely to be more precise, but perhaps no more accurate, while the latter is the more common method.

Hot water usage by various household activities is shown in Figures 34 - 38.

In some cases, the possible use considerably exceeds the normal capacity of the cylinder.

## Sizing a storage water heater

Installing the appropriate size of water heater is important, not only in a new house, but also when a water heater is being replaced in an older house. Too often replacement of “like for like” is made as the cheapest option when, for a relatively small increase in expendi-

<b>Example 1: Low use</b>			
Shower	flow 6 litres/minute 4 showers at 7 minutes	=	100 litres
Dishwashing		=	30 litres
General		=	30 litres
Clothes washing		=	0 litres
<b>Total</b>		=	<b>160 litres</b>
<b>Example 2: High use</b>			
Shower	flow: 12 litres/minute 4 showers at 7 minutes	=	200 litres
Clothes washing	2 hot washes per week	=	70 litres
Dishwashing		=	30 litres
General		=	30 litres
<b>Total</b>	<b>for non-washdays (5 days)</b>	=	<b>260 litres</b>
	<b>for wash days (2 days)</b>	=	<b>330 litres</b>

Figure 33: Daily hot water use

ture, the system can be upgraded to improve the efficiency and quality of service and reduce running costs.

A storage water heater should be sized to take account of the worst season of the year (coldest weather and hence greatest standing losses from the cylinder and coldest mains water supply temperature), the hot water demand of the occupants (including visitors), the peak hot water demand, the recovery rate of the heater after use and the energy supply option selected.

There are several methods for estimating demand. One is by household use, adding showers and dish washes and clothes washes and other uses to get a daily total. This method is particularly relevant to systems operating under night rate heating where a single cylinder full of hot water must provide the whole day's demand. This is illustrated in Figure 38.

Where a system has a continuous energy supply one can estimate the size of cylinder in terms of peak demand and recovery time. In the extreme case of a system with sufficiently high power, no storage is required.

### Availability of hot water

The amount of usable hot water which can be obtained from a cylinder varies with the storage temperature and the temperature of use. It is also influenced by the recovery rate, which is in turn influenced by the power of the heating system. For example electric storage water heaters, especially those in older systems, are often fitted with 1.5 kW or 2 kW elements and have low recovery rates that have little influence on the effective capacity of the system at high draw-off rates. Gas

Appliance	Estimated water use	litres of stored hot water used (65°C)
<b>Hand Basin</b>	Allow daily up to 6 litres at 40°C per person	3 - 4 litres per person or 10 - 15 litres for a family
<b>Bath</b>	Allow for family members or visitors who are likely to take baths.  A bath can hold from 50 - 200 litres of water at 40°C. Allow 100 litres of 40°C water/bath for a large bath, 50 litres for a small bath.	40 - 80 litres per bath  A spa bath has special requirements - refer to manufacturer's information

Figure 34: Water usage — bathroom

Shower	Shower head flow											
	6 litres/minute			10 litres/minute			15 litres/minute			20 litres/minute		
	Minutes			Minutes			Minutes			Minutes		
	5	10	15	5	10	15	5	10	15	5	10	15
1 Shower	17	34	50	28	56	84	42	84	126	56	112	168
2 Showers	34	67	100	56	112	168	84	168	252	112	224	336
3 Showers	50	100	151	84	168	252	126	252	378	168	336	504
4 Showers	67	134	202	112	224	336	168	336	504	224	448	672
5 Showers	84	168	252	140	280	420	210	420	630	280	560	100
6 Showers	100	202	302	168	336	504	252	504	756	336	672	117

Assuming:

- Hot water storage temperature = 65°C.
- Shower mixed water temperature = 40°C.
- Cold water temperature = 8°C.

Shaded areas exceed the capability of a 180 litre storage cylinder

Figure 35: Shower hot water use — litres

storage systems, on the other hand, have a high input power and recovery rate and the total amount of water that can be taken from the cylinder at a single draw-off can exceed the nominal capacity of the cylinder. This is illustrated in Figure 39.

It can be useful to detail the water usage for a given family using a table of the kind shown in Figure 38 and the data in Figures 34 - 37 to estimate the total and peak hot water use.

These figures can be translated into storage requirement using Figure 38. In many households inadequate storage is compensated by using a higher storage temperature. As has been pointed out elsewhere, high water storage temperatures can result in physical risk and energy wastage.

Figure 40 indicates the multipliers for the amount of shower temperature (42°C) water that can be obtained from a given cylinder size at various delivery temperatures. These are based on complete stratification, no recovery during the period of use, and a cold water supply of 10°C.

It should however be kept in mind that if storage temperatures in excess of 55°C are used, appropriate

safety precautions such as the use of a tempering valve need to be taken.

As an overall check on sizing in general one should expect a total of about 40-60 litres of hot water (60°C) per person per day. Peak use over, say, a 2-hour period is more difficult to estimate, but can be as high as 300 litres for a 4-person household, depending on the household routine. An appropriate cylinder size is usually somewhat above one full day's use.

Typical water supply temperatures range from 5°C to 15°C. Since the delivery temperature from the cylinder is usually about 60°C, the temperature rise required ranges from 40°C to 55°C and the energy requirement can therefore vary by as much as 30% for the same supply service in terms of volume of hot water delivered. For a family home using 200-300 litres per day of water at 60°C, the energy requirement can range from 10 to 20 kWh per day.

The amounts of water likely to be used by various household appliances are shown in Figures 34 to 37.

### References and Notes

- 1 BRANZ. *Study Report 91*, August 2000

Appliance	Estimated water use	Litres of stored hot water used (65°C)
<b>Sink (no dishwasher)</b>	Allow daily two uses of 20 litres, plus 5 litres of general use of 60°C water	45 litres per day
<b>Sink (dishwasher used for main wash)</b>	General use	5 to 10 litres per day
<b>Dishwasher Cold fill :</b>	Many dishwashers have the option of cold fill which does not use water from the household water heater.  Others may be plumbed to the cold water supply only	0 litres
<b>Dishwasher Hot fill :</b>	Refer to the manufacturer's information.  As a guide, most dishwashers use 20 to 40 litres of water at 60°C per cycle	20 to 40 litres per cycle

Figure 36: Water use — kitchen

Appliance	Estimated water use	Litres of stored hot water used (65°C)
<b>Tub</b>		Allow 5 litres daily
<b>Washing Machine</b> <b>Cold fill only:</b>	Decide whether hot or cold washes are likely.  Can hot washes be done in the early hours of the morning giving the water heater time to recover?	No use of hot water.
<b>Washing Machine</b> <b>Warm wash (20°C):</b>		Up to 15 litres per wash
<b>Washing Machine</b> <b>Hot Wash</b>	Refer to manufacturer's information - most washing machines use 50 - 90 litres of water at 60°C per wash cycle.	Allow 40 to 90 litres per wash

Figure 37: Water use — laundry

Use	Stored hot water used <sup>1</sup> Litres at 65°C	No. of people using (or no. of uses)	Total <sup>2</sup> Litres	Peak Demand <sup>3</sup>	
				morning	evening
<b>BATHROOM 1</b>					
Hand basin					
Bath					
Shower					
Spa bath					
<b>BATHROOM 2</b>					
Hand basin					
Bath					
Shower					
<b>KITCHEN</b>					
Sink general					
Sink dishwashing					
Dishwasher					
<b>LAUNDRY</b>					
Tub					
Washing Machine					
		<b>Total litres of hot water (65°C)</b>			

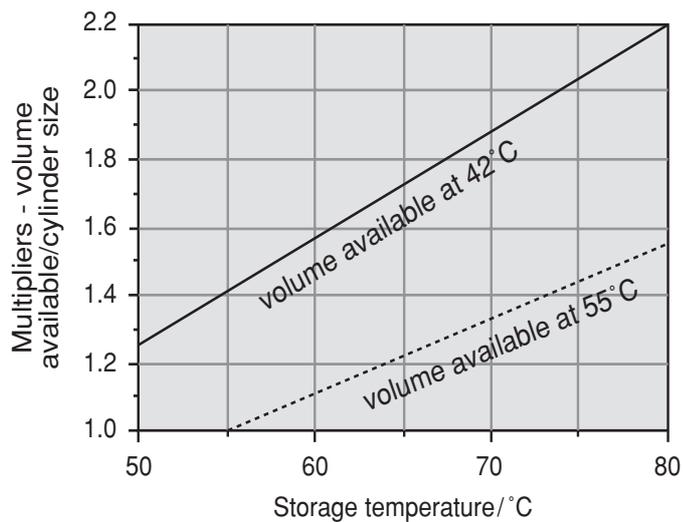
- 1 Refer to manufacturers' literature for hot water delivery performance. Australian figures are based on 45°C rise and 60°C hot water, so increase quantities given in the previous guidelines by 10%
- 2 The total requirement for all uses should be used where water heaters are on electric night rates as all uses throughout the day will affect the amount of stored water available. It should also be used for water heaters with a variable recovery rate such as solar systems.
- 3 Maximum likely use of hot water over a one to two hour period. This is the critical factor for water heaters on continuous supply (as replacement water is reheated immediately).

Figure 38: Template for estimation of hot water requirement (24 hours)

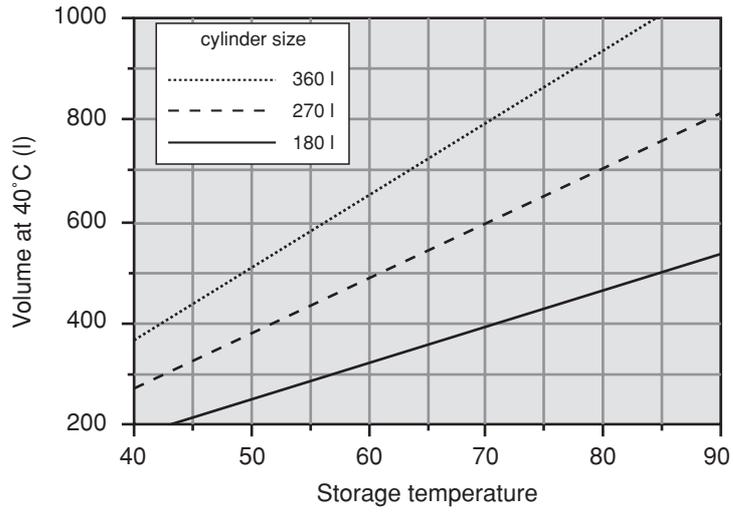
Energy supply	Capacity litres	Delivery litres
<b>Gas</b>	135	220
	145	260
	170	270
	185	300
<b>Electric</b>	135	135
	180	180
	250	250
	250 <sup>1</sup>	300
	270	270
	270 <sup>1</sup>	320
	300 <sup>1</sup>	375

<sup>1</sup> For cylinders with twin 3 kW elements and upper element on continuous supply  
 Assuming: Electric hot water storage temperature = 65°C, hot water delivery temperature = 60°C and cold water intake temperature = 15°C.

**Figure 39: Hot water delivery from storage cylinders**



**Figure 40: Typical multipliers for cylinder size/storage temperature**



**Figure 41: Available volumes at 40°C assuming perfect stratification and no recovery during the drawoff period**

# Chapter 5

## Water Pressure Control

Pressures in domestic water systems are usually presented in units of kilopascals (kPa) or in head of water, that is the height of free water column which would create the measured pressure. These units are related within about one percent by the equation:

$$1 \text{ m head} = 10 \text{ kPa}$$

Water comes from the street main at a pressure which can vary from time to time during the day and from locality to locality. The normal range is from about 300 kPa to 1200 kPa.

Because water expands on heating some provision must be made to allow for the volume change which accompanies heating. Without such provision, excessive pressures will develop leading to damage to the cylinder and possibly even to the pipe-work. Conversely in some systems such as two-storied buildings with the cylinder upstairs, drawing water in a badly designed system can cause air to be drawn into the system via the header pipe. In extreme cases, it is even possible for the pressure in the cylinder to fall below atmospheric and this in turn can cause the cylinder to partially collapse.

Some pressure is required to maintain water supply to the delivery devices such as taps and shower mixer valves. The pressure needed depends on the rates of flow required, the length and diameter of the pipes and the design of the taps and valves. This pressure is generally much lower than the pressure available from the street main supply.

Domestic water distribution systems usually operate at pressures ranging from 2-3 m head (20-30 kPa) up to 50 m head (500 kPa).

The three main classes of pressure systems used in New Zealand are determined largely by history and by the standards regulating storage cylinder design. In the diagrams only the essential features are shown. Full details of some systems showing all valves, filters and controls are given later in this chapter.

### Header Tanks

The pressure in the hot water pipes can be maintained in several ways. The oldest and still a frequently used method, is the header tank. This method is still popular

and is widely used in systems with wetback heating in which “open venting” is mandatory. A typical header tank system is illustrated in Figure 42.

In a header tank system, water from the main supply is fed to a tank situated at a height above the hot water outlets sufficient to provide the required head (and hence flow). The water level in the header tank is maintained by a ball-cock.

This system provides the driving head for flow in the hot-water supply and ensures the physical separation of the domestic system from the water main. Its chief virtue is its simplicity. Expansion on heating is mostly taken up by movement of cold water back into the heater tank, rather than by overflow from the vent pipe.

The water head available is determined by the height of the ball cock above the delivery outlet and is usually from a couple of metres (20 kPa) to the maximum for a standard low pressure cylinder 7.6 m (75 kPa).

The chief defect of the header-tank system is the relatively low driving head available, especially in houses with low stud heights and low roof pitch, which in some cases restricts the head available to a shower rose to less than a metre.

A minor variation of the open vented arrangement has the vent pipe exhausting into the header tank as shown in Figure 43.

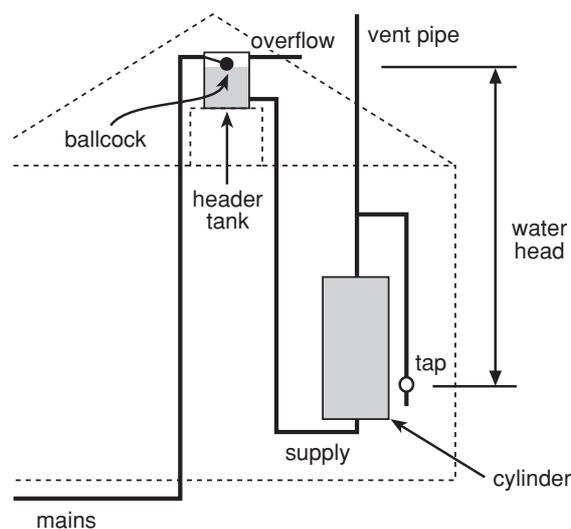


Figure 42: Typical header tank system

## Pressure reducing valves

It later (in the 1970s) became more common to use a pressure reducing valve instead of a header tank. Figure 44 illustrates a typical open vented system using a pressure reducing valve.

The mains supply is passed through a pressure reducing valve and then directly into the cylinder. The valve delivers water to the cylinder whenever the pressure on the cylinder side falls (e.g. as water is drawn from the cylinder). In the version shown, the cylinder remains vented directly to the atmosphere. The head available is determined by the height of water in the vent pipe.

There are two standards for the construction of low pressure cylinders allowing for maximum pressures of 7.6 m and 12.2 m head. Low pressure cylinders (up to

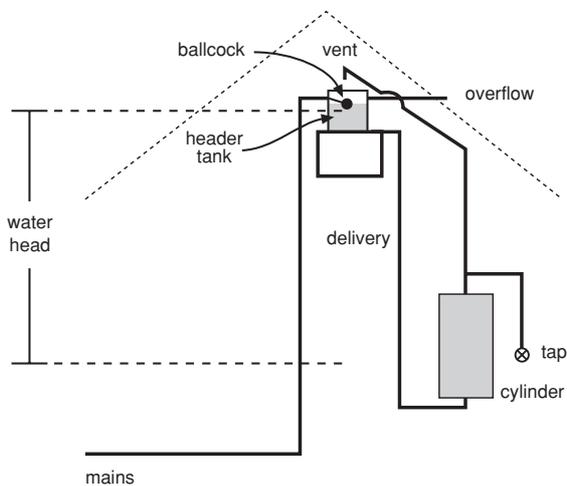


Figure 43: Header tank with internal header pipe

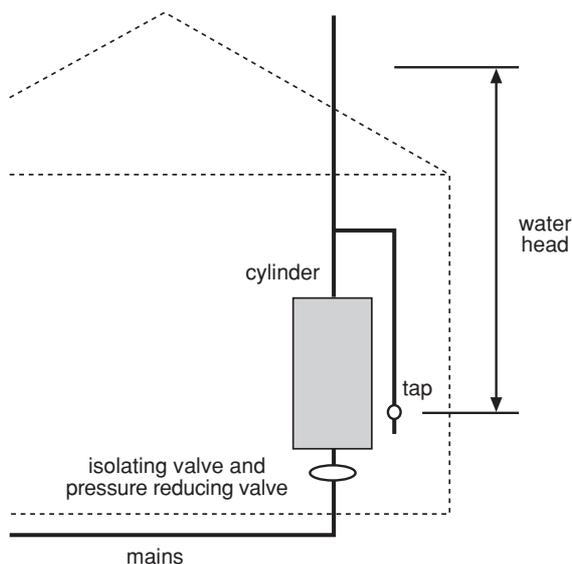


Figure 44: Open vented system

120 kPa) are designed to a standard which allows for a maximum head of 12.0 m. However, as has been pointed out, the actual driving head may be considerably less than this. For example, when a header tank is in the attic space above a shower, the head is the vertical distance between the water level in the header tank and the shower nozzle, and this might be as little as 0.7 m. If the plumbing layout and the plumbing fittings are not chosen appropriately in terms of pipe sizes, the positioning of other outlets and the choice of nozzle, then the shower outlet will be sensitive to the operation of other outlets in the house and indeed to the amount of water in the header tank. This will result in the shower running hotter or colder as other taps in the house are turned on or off and in the total flow changing as the amount of water in the header tank changes.

As mentioned earlier, in some open-vented systems the flow can create a pressure distribution in the pipework that draws the water levels in the header pipe below the junction with the hot water take-off. In such cases, air is drawn into the hot-water line and an intermittent or spluttering flow is achieved at the tap or shower. This problem can sometimes be offset by using dual pressure reducing valves to increase the flow from the mains.

On the other hand, a low pressure system can operate perfectly satisfactorily if the plumbing fittings are well chosen and the pipe layout is carefully planned. For example, steps should be taken to ensure that the shower is isolated from other outlets and that equal pressures are available to the cold and hot inputs to the shower. Typical arrangements to achieve this are shown in Figure 45.

Most low pressure systems use copper cylinders which have been known to last for 50 years or more.

The age distribution of electric storage cylinders, as found in the BRANZ household condition survey, is shown in Figure 46.

## Open vented systems

In systems with simple pressure reducing valves, expansion of the water on heating is taken up by movement of water up the vent pipe. If a cylinder is filled with cold water and then heated (for example when all the hot water in the cylinder has been used), this expansion can exceed the capacity of the vent pipe and water flows onto the roof. The overflow can “waste” several percent of the energy used for water heating.

“Open vented” systems of the types shown above are mandatory for cylinders in which water is heated by a wetback.

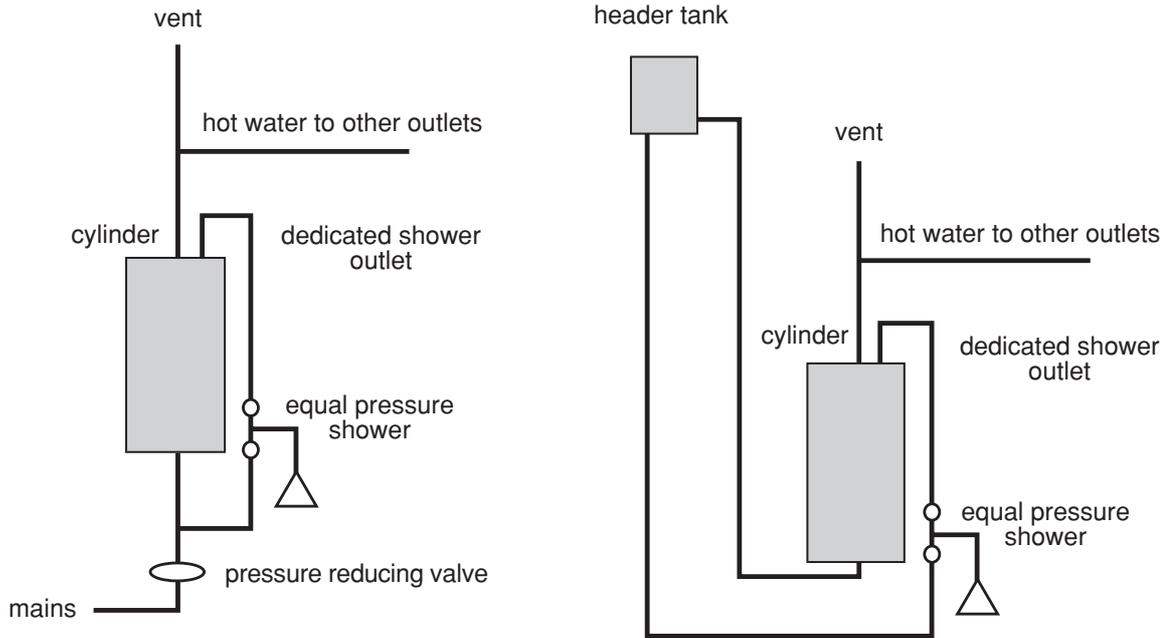


Figure 45: Possible equal pressure shower plumbing layouts

### Valve vented systems

Operating the hot water system at a higher pressure can reduce the extent of the interaction between the various outlets and in particular can reduce the fluctuations in shower pressure and temperature when other taps in the house are used.

Two forms of higher pressure system are available in New Zealand, a low-pressure system with heads of up to 12.2 m (120 kPa, 18 psig) and a high-pressure system, often referred to as mains pressure, usually up

to about 35 m (350 kPa, 53 psig) or 50 m (500 kPa, 74 psig). Both use a pressure limiting valve to control the inlet to the cylinder.

Cylinders designed for 12.2 m head are usually made of copper, which is rather heavier gauge than that used for low pressure 7.6 m cylinders. Mains pressure cylinders are usually made from steel coated internally with a vitreous enamel lining, or from stainless steel. Because of the higher head it is not usually convenient to have an open vent via a stand pipe and the systems are vented through a pressure relief valves fitted to the top and bottom of the cylinder.

Some suppliers use a combined temperature/pressure relief valve (TPR valve) which exhausts water from the cylinder when either the pressure OR the temperature exceeds preset values. This is mandatory on high-pressure cylinders. In many systems the pressure control valve on the inlet to the cylinder is part of a multi-purpose package that provides matched filter/stop valve, non-return valve, pressure control valve, tempering valve, cold water expansion valve and drain valve in a kit.

The cold water expansion valve is a pressure relief valve set to discharge below the main pressure relief valve so that the normal expansion of the water as it heats up is compensated by venting the coolest water at the bottom of the cylinder rather than the hotter water at the top of the cylinder. Typical arrangements of valves on valve vented systems are shown in Figure 47.

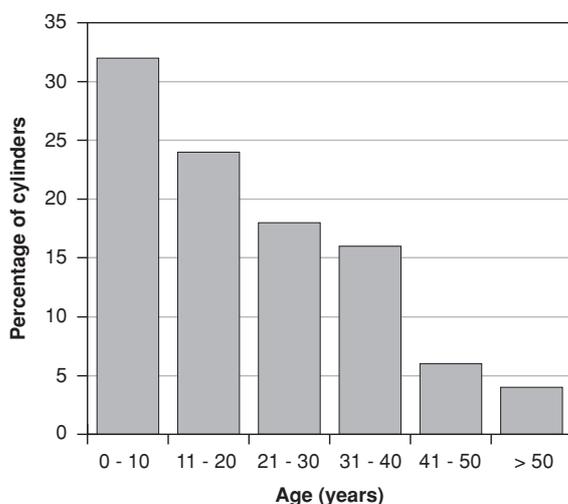
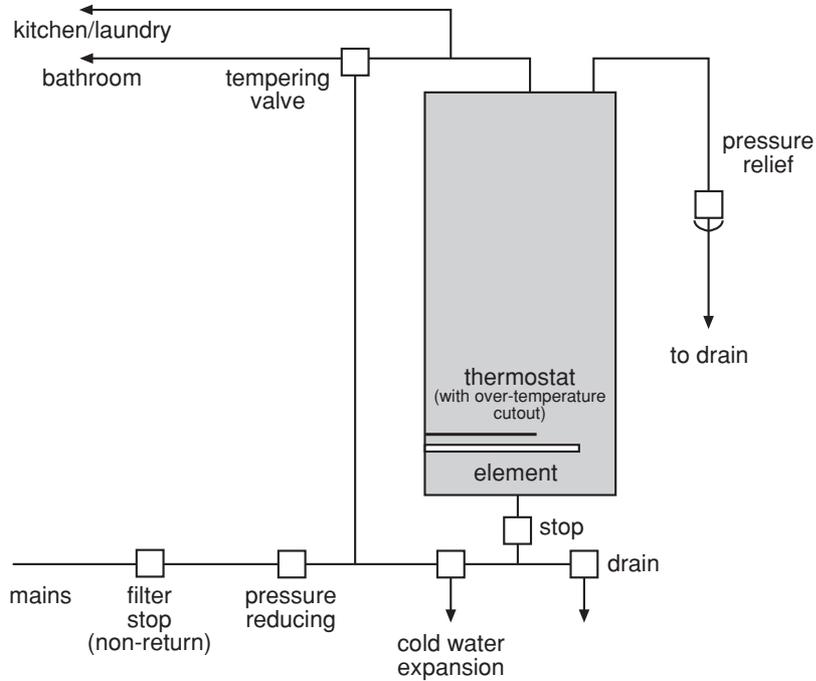


Figure 46 : Age distribution of electric storage cylinders in New Zealand

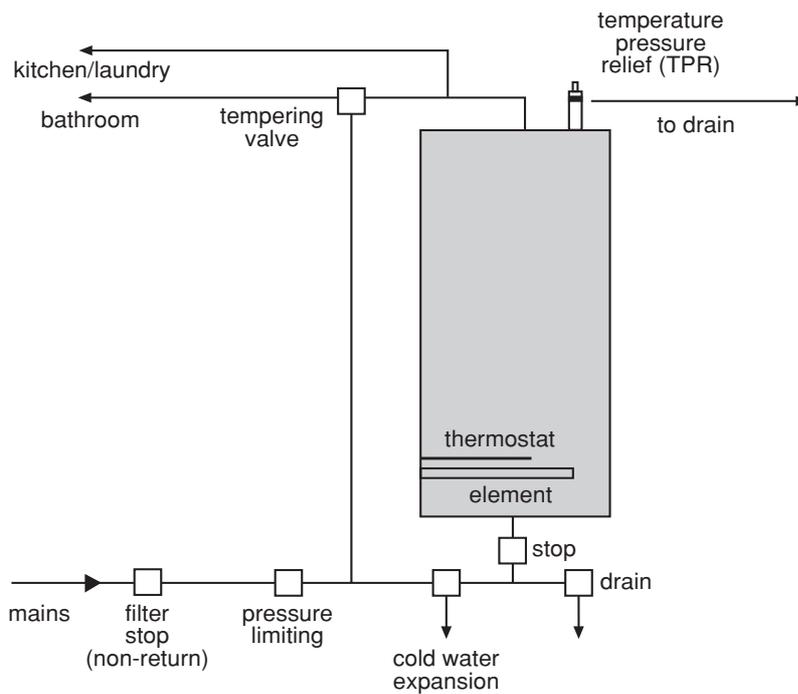
The arrangement shown in Figure 47a can be fitted to low pressure 7.6 m cylinders as an alternative to or as a modification to open vented and header tank systems. Such a modification can significantly increase the performance of showers both in terms of total flow and

flow and temperature fluctuations induced by other outlets.

Cross sections of typical examples of various valves used in pressure controls are shown in Figures 48 to 51.



**Figure 47a: Low pressure (7.6 and 12.2 m) valve vented systems**



**Figure 47b: Mains pressure valve vented system**

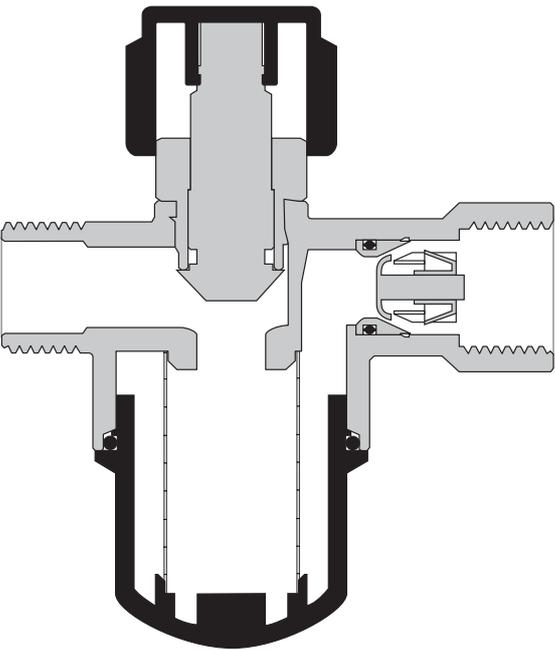


Figure 48a: Filter stop non-return

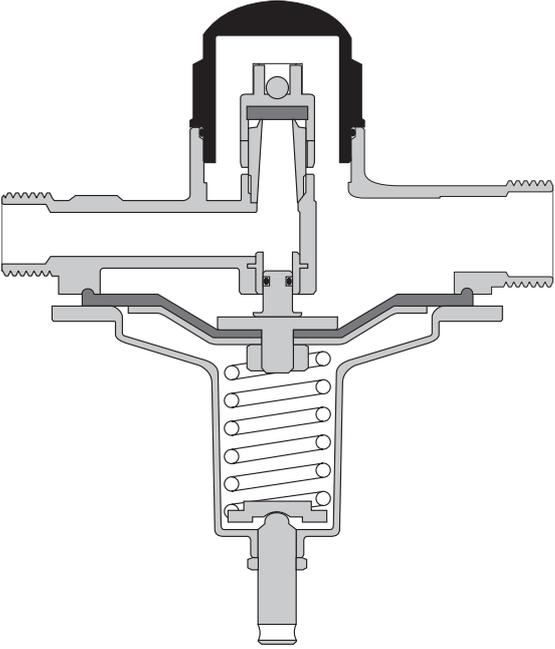


Figure 48b: Pressure reducing valve

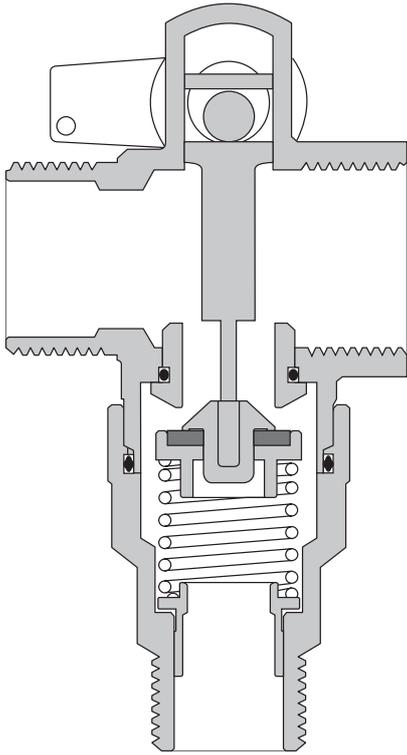


Figure 49a: Cold water expansion valve

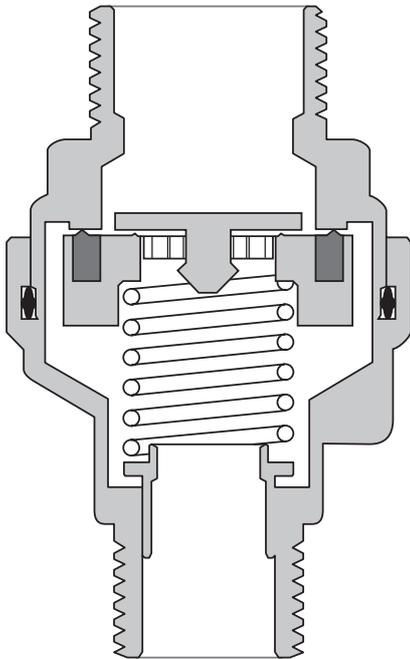


Figure 49b: Medium or low-pressure relief valve



Figure 50a: Temperature-pressure relief valve

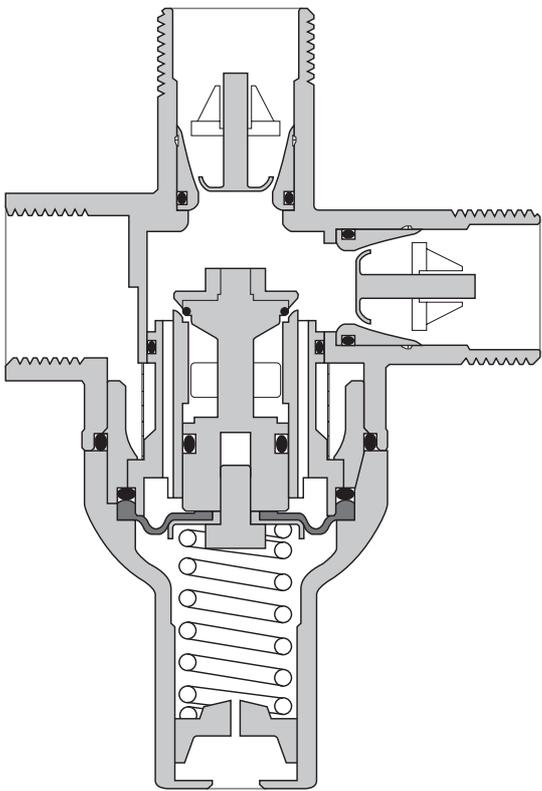


Figure 50b: Tempering valve



Figure 51: 5-way port

# Chapter 6

## Storage Cylinders

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The first question one should ask about cylinders is “why does a hot water system have a cylinder”? Why do we not simply heat the water on its way to the tap as it is required? The answer to this is that for **electrically heated water**, the power required is greater than can conveniently be provided by a normal household wiring system. For example a good shower uses about 8 litres per minute of water at about 40°C. To heat this flow from mains water at say 10°C would require a power input of more than 16 kW, considerably more than is normally available from single-phase household wiring.

It is more practical to use a lower power over a longer time to make sufficient water for the shower in a storage cylinder from which it can be drawn later at a suitable rate. Thus a 5 to 10 minute shower using 40 to 80 litres of water can be drawn from a cylinder in which it had been heated by a 3 kW element over a period of 1.5 to 3 hours.

There are other advantages to using a storage cylinder. The use of a central storage cylinder also means that hot water can be drawn simultaneously at several points in the house without overloading the system.

Finally, the total load on the electricity supply system can be distributed in time. For example, water can be heated at night when the load on the power supply is low (“night rate supply”) and used later in the day. In most New Zealand households the hot water circuit is controlled by the power supply company through “ripple control” which enables them to cut off supply to the hot water cylinders at times of high load.

Cylinders are designed to heat and store a useful quantity of water ready for immediate use. They operate on a displacement principle, in which hot water is drawn from the top of the cylinder, while cold water enters at the bottom. The hot water, being less dense than cold water will float on top of the cold water. The cold water inlet is usually designed with a deflector (baffle) so that the cylinder contents are not stirred and mixed by the incoming stream. This “stratification” is maintained until power is available to the heating element whereupon the lower cold water is heated and rises to the upper part of the cylinder. The boundary between hot and cold water descends until it reaches the thermostat whereupon the power supply to the

element is interrupted until more cold water is introduced to the cylinder.

The concept of the storage hot water system is to generate and store sufficient hot water to satisfy likely demand over some defined period. The volume of storage is determined by the likely use and the recovery rate.

This in turn is determined by the relation between the power of the heating element and the cylinder size. A common choice of cylinder size is that which will supply approximately one day’s need and the element is frequently sized to reheat one whole cylinder full in 4 to 6 hours.

The contribution of cylinder and element sizes are detailed in Chapter 4, under “choice of cylinder”.

Hot water cylinders can be made from a wide diversity of materials such as copper, stainless steel, enamelled steel, and plastics. In New Zealand, the most common types are copper and enamelled steel, although the use of stainless steel cylinders is growing.

### **Low pressure cylinders (7.6 and 12.2 m head)**

Copper cylinders used for low pressure supply consists of a cylindrical barrel to which two dome ends are brazed and into which threaded bosses are brazed to attach all the required external fittings.

The cylinder is placed inside a galvanised steel outer case and the space between is filled with insulating material. Older style cylinders used flock or fibreglass insulation and more modern cylinders use mainly polyurethane foam which has a higher insulating capacity for a given thickness.

Low pressure cylinders are designed to a standard that allows for a working pressure up to 7.6 m head (75 kPa, 11 psig). Cylinders are also available for pressures up to 12.2 m head (120 kPa, 18 psig). These differ from the low pressure cylinders in being made of a heavier grade of copper.

The structure of a typical copper hot water cylinder is shown in Figure 52.

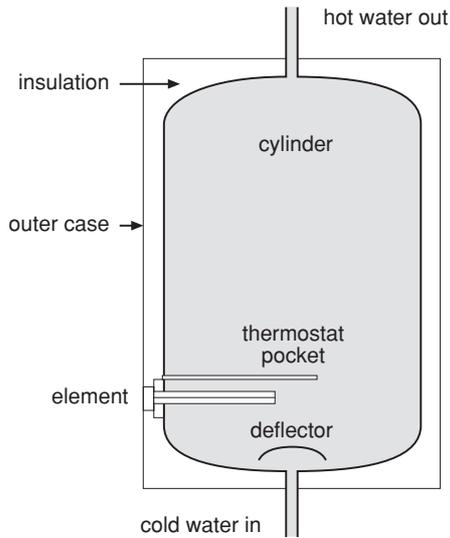


Figure 52: Typical simple cylinder

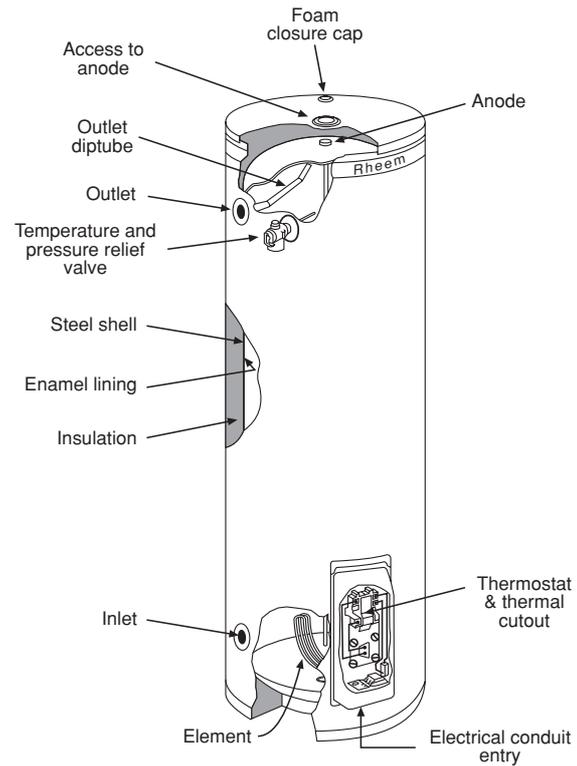


Figure 53: Steel/enamel cylinder

### High pressure cylinders

High pressure cylinders are usually made of steel with an enamel lining. The steel is heavy enough to withstand the higher pressure and is protected from corro-

	Pressure Type			
	“Mains”	12.2 m head	7.6 m head	Open Vent ≤ 3.7 m head
<b>Pressure<sup>1</sup></b>	350-550 kPa	120 kPa	75 kPa	≤ 37 kPa
<b>Flow</b>	High	Medium/High	Medium	Low
<b>Pipe Size</b>	Small (c 15 mm)	Medium (c 20 mm)	Medium (c 20 mm)	May need larger (> 20 mm)
<b>Showers</b>	Very Good to excessive <sup>2</sup>	Good	Adequate	Often inadequate
<b>Compatibility with imported taps and mixers</b>	Yes	Often	Needs care in choice	Needs care in choice
<b>Tempering Valve</b>	OK	OK	OK	Select appropriate valve
<b>Maintenance</b>	Valves may need maintenance			low
<b>Durability</b>	12 - 20 years	20 - 40 years	20 - 50 years	20 - 50 years
<b>Use of Water<sup>3</sup></b>	High	Low		Low

1 Often systems are fitted with pressure limiting arrangements to keep the pressure constant, as town pressure can reach 1,000kPa.

2 It should be noted that water use is not just dependent on pressure.

Figure 54 : Comparison of mains pressure and low pressure water heaters in terms of their general performance

sion by a vitreous enamel (“glass”) lining. The enamel is fused onto the steel at high temperature and is brittle at normal operating temperatures. For this reason care must be taken in handling these cylinders to avoid severe mechanical shocks which could damage the lining. To further protect the cylinder from corrosion arising from minor cracks in the lining, steel cylinders are usually fitted with a “sacrificial anode” which is designed to form an electrochemical cell with any exposed steel. This cell acts in such a way that the anode dissolves in preference to the steel thus protecting the body of the cylinder.

Manufacturers of steel cylinders usually provide information on the expected life of the anodes and a suggested replacement interval. The life of the anode depends to some extent on the quality of the local water supply and information should be sought from manufacturers for particular cylinders in particular localities. Provision for access to replace the sacrificial anode should be (but is often not) made at the time of installation of the cylinder.

Vitreous enamel linings can also be damaged by high temperatures and manufacturers provide information on the maximum temperatures to which particular cylinders should be exposed. For many domestic grade cylinders this is in the range 70°C to 75°C. However purchasers should seek specific information on particular cylinders.

High pressure cylinders are made in a range of sizes and with fixed fittings for general use and it is not possible to modify them after manufacture by adding extra ports or other fittings.

Copper cylinders are available in a wide range of sizes and dimensions. The common sizes for the primary supply are 180, 225, 270, 360 and 450 litres (40, 50, 60, 80 and 100 gallons) The range of dimensions available is shown in Figure 55.

Heat loss from the cylinder occurs through the insulat-

ing jacket and via the fittings. Electric cylinders are available with various levels of insulation. This can often be deduced from the dimensions of the outer case in relation to the volume of water contained by the cylinder. The better cylinders usually have 50 mm of polyurethane foam between the cylinder and the outer casing. The heat loss from a cylinder insulated to the standard described in NZS 4602:1988 and kept at 55.6°C above its surroundings is described by the relations:

Capacity	heat loss in kWh/24hrs
90 litres and less	$0.0084L + 0.4$
90 litres and more	$0.0048L + 0.72$

Where L is the water volume in litres.

For a 270 litre cylinder this is 2.0 kWh/day.

While the losses from a modern cylinder are generally less than 20% of the total energy used to provide the hot water supply, the losses from older cylinders can be much higher. In many cases, these losses can be significantly reduced by using an “insulating blanket”, usually made of fibreglass with a foil-coated outer skin.

Cylinder blankets can be obtained from many power companies and energy shops.

The size of the element relative to the cylinder capacity determines the time it takes to heat a cylinder full of water to working temperature. Heating times for typical cylinder sizes based on an inlet temperature of 15°C and a final temperature of 65°C are shown in Figure 56.

From the above it can be seen that a 3 kW element will heat a 270 litre cylinder from 15 °C to 65°C in about five hours to provide the daily needs of a typical 5 to 6 person household. The performance of other combinations of element and cylinder size can be read from the graph.

Capacity (litres)	Copper		Mains (vitreous lined)	
	Diameter (mm)	Height (mm)	Diameter (mm)	Height (mm)
180	460, 510, 540, 560	1910, 1500, 1370, 1200	430*, 530, 538*, 610	1720, 1720, 1166, 1166
225	540, 560, 610	1690, 1500, 1280	—	—
250	—	—	538*, 610	1560, 1560
270	540, 560, 610	1980, 1760, 1490	—	—
300	—	—	538*, 610	1825, 1825
360	610, 710	1980, 1400	—	—
450	710	1700	—	—

\* lower grade insulation

Figure 55: Typical storage cylinders dimensions

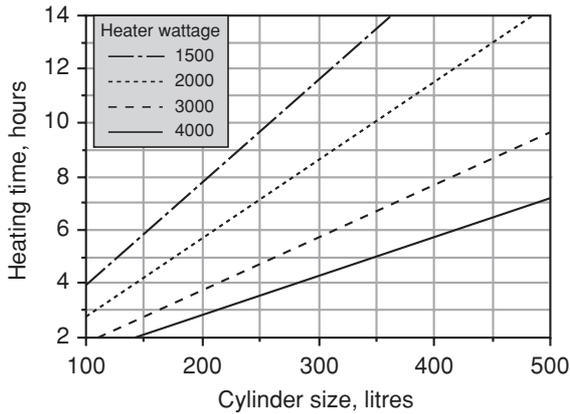


Figure 56: Heating times for different cylinders

Stainless steel cylinders are made to withstand mains pressure and have similar configurations to copper cylinders. They do not need special coatings or anodes to prevent corrosion. They are generally the most expensive of the cylinder types but have a reputation for longevity.

### Additional features of hot water cylinder design

In order to improve recovery time it is possible to have cylinders with more than one element as shown in Figure 57.

In this arrangement an extra element is fitted in the upper part of the cylinder so that a small amount of water may be heated quickly. The quick recovery element is controlled by a “lock-out” thermostat initiated by a push button. The water above the element is

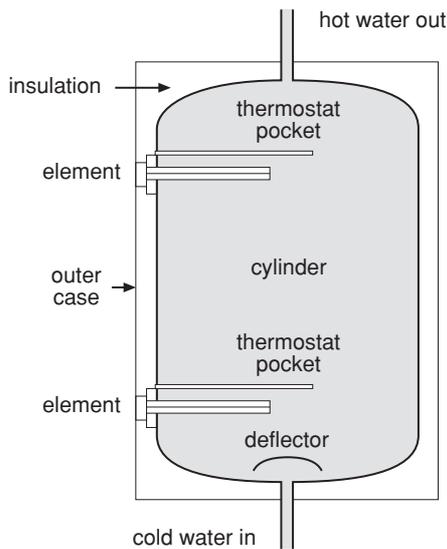


Figure 57: Quick recovery system

heated until it reaches the set temperature of the thermostat, which switches off and stays off until the reset button is pushed again. In this way a 3 kW element heating only the top 25% of a 270 litre cylinder will produce useable water say for a shower at 42 °C from cold in about 30-45 minutes, depending on the cold water supply temperature

An alternative use of two element cylinders is in situations where the use for hot water changes dramatically from time to time, for example in a house which is normally occupied by say two people but is large enough to accommodate six. In this case one can use a cylinder in which the top third is served by one element and thermostat and the whole cylinder by a normal element and thermostat. When there is low occupancy only the upper part of the cylinder is used and at high occupancy control is switched from the upper element/thermostat combination to the lower set as shown in Figure 58.

### Cylinders with internal heat exchange coils

The high cost of copper prevents the use of very thick walled vessels to make a simple all-copper high pressure cylinder. This problem has been met by some manufacturers by using a heat exchanger between the high pressure flow and the low pressure storage as shown in Figure 59.

Low pressure water is stored in a conventional copper cylinder which is heated directly by the element. High pressure water flows in the coil and is heated from the

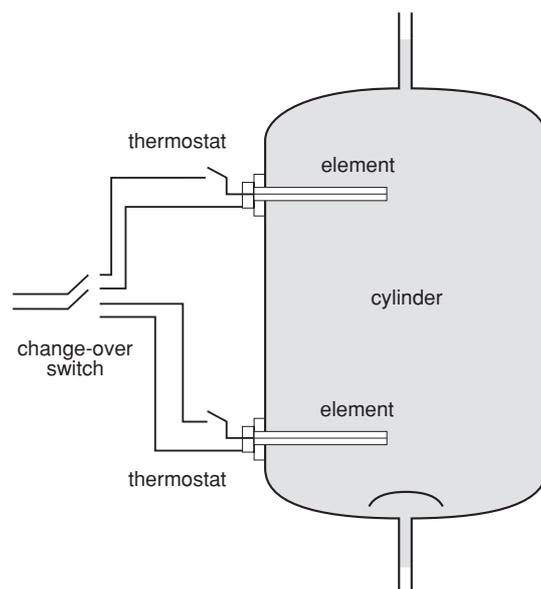
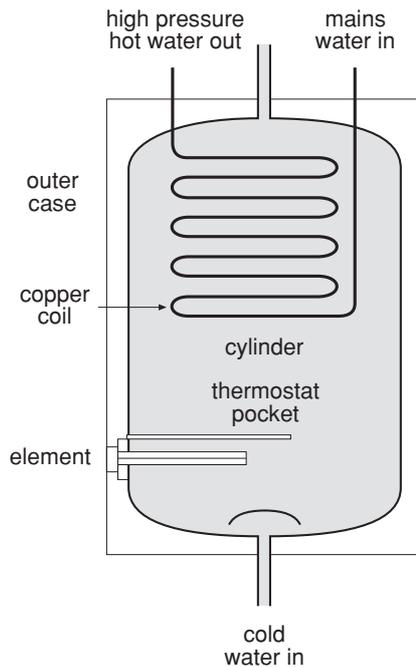


Figure 58: Two element cylinder



**Figure 59: Low pressure cylinder with high pressure coil**

main body of the cylinder. In this way high pressure hot water is provided for reticulation whilst energy storage is achieved with low pressure water.

A common use of such cylinders is in providing high pressure water to showers via the coil, while low pressure hot water is supplied to the remainder of the house directly from the main body of the cylinder.

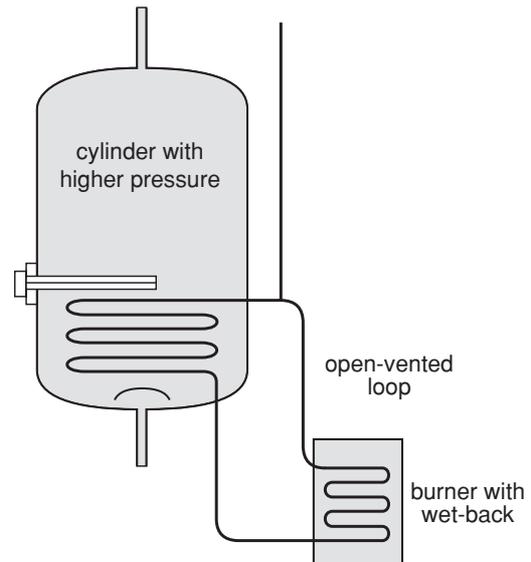
Because of the limited heat transfer capacity of the coil, dual-pressure systems are often operated at a higher cylinder temperature than simple systems. This, in turn, incurs higher heat loss.

Coil-in-cylinder heat exchange systems are sometimes used in reverse with low pressure water in a coil immersed in a high pressure cylinder. This arrangement is used where a high pressure system is coupled to a “wetback” which is required by law to be open vented to atmosphere, as shown in Figure 60.

## External water heaters

In New Zealand electric water heaters are almost always installed in a cupboard inside the dwelling. In Australia both gas and electric water heaters are commonly fitted outside the house.

In New Zealand more gas water heaters are being installed outside and this could, following Australian practice, lead to a demand for externally mounted electric water heaters. The advantage is that external



**Figure 60: Valve-vented cylinder with open-vented wetback**

installation frees up floor or cupboard space and simplifies installation especially when the time comes for replacement.

The disadvantages are that greater standing losses are incurred, and exposure to the weather can lead to greater maintenance and reduced appliance life. The benefits of the heat loss from the cylinder to an airing cupboard and in winter as a minor supplement to space heating are lost but with modern insulation these benefits are in any case quite small.

A compromise approach which frees up floor space while avoiding some of the disadvantages of external installations is to locate the hot water cylinder in the roof (attic) space. This can, in some cases, also allow placement which simplifies the plumbing and allows more direct connection between cylinder and outlets.

## Under bench cylinders

Where a quick response for small volumes and infrequent use are required, it is often useful to install a small cylinder of 10 to 25 litres capacity close to a single outlet rather than incur the delay in delivery and energy waste which accompanies a long pipe run from cylinder to tap. This is often done in kitchens or for handbasins in bathrooms that are some distance from the main cylinder. These cylinders are often of the “push-through” pattern with the tap on the inlet side of the cylinder (see Figure 61). This ensures that the cylinder itself is at low pressure and is vented for water expansion but requires no controlling valves.

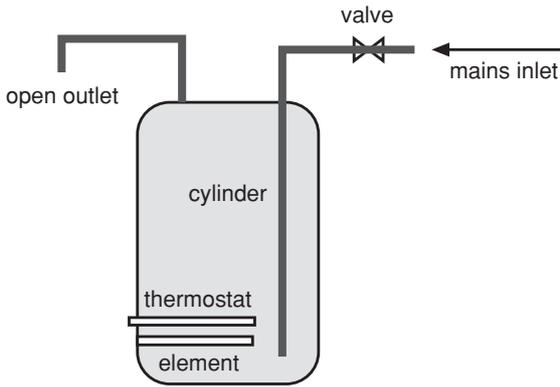


Figure 61: Push through cylinder

## Gas storage cylinders

As with electric storage water heaters, gas storage heaters hold a useful amount of heated water in an insulated vessel. Cold water entering at the bottom of the cylinder displaces hot water drawn from the top of the cylinder to the taps. A gas burner is located near the bottom of the cylinder and heat transfer to the water takes place from the hot combustion gases as they travel up the flue from the burner to the exhaust. The water temperature is controlled by a thermostat in the cylinder which modulates the gas flow. Ignition of the gas is ensured by either a permanent pilot light or by an electronic ignition which is initiated by the thermostat in conjunction with the gas flow.

An important aspect of the design of gas storage heaters is to achieve good heat transfer between the flue gas and the water in the cylinder. To this end various flue/heat exchanger designs have been used some of which are shown in Figure 62.

The most commonly used design is the single flue, in which the heat transfer area is the bottom of the tank and the internal surface of the flue. The heat transfer area can be increased by using a larger diameter flue or by using more than one flue. Even more heat transfer surface can be obtained in the “floater” and “semi-floater” designs in which flue space is provided around the wall of the cylinder. The more complex designs are often used in commercial water heaters where a rapid recovery rate (high thermal input) is required.

Typical burners used in gas storage heaters give 25-40 MJ/hr and this corresponds to a heat input to the water of about 6-9 kW. The higher heat input to gas cylinders relative to electric ones gives them a higher recovery rate and this in turn means that for a given service (in terms of draw off) the gas cylinder can be smaller in volume.

A further, minor, advantage of gas water heating is that

gas supplies are not subject to unannounced interruption by the energy supply company.

## Boiling water units

Boiling water units are used to provide near boiling water (usually at 96°C to 97°C) mainly for beverage making in shops, offices, clubs, hotels, motels, and commercial and domestic kitchens. They are also used to provide very hot water for medical and dental surgeries.

Most units are wall mounted and have capacities from 5 to 25 litres although some commercial units can be as large as 400 litres. They are generally designed as atmospheric (low) pressure devices with a large element power to water volume ratio for very quick recovery. Some domestic models can be fitted underbench. Their control systems are often quite different from conventional domestic water heaters with float valves, flow control nozzles, electronic thermostats and steam switches.

## Other cylinder configurations

The special cylinder configurations used with solar energy boosted systems are described in the section dealing with these systems.

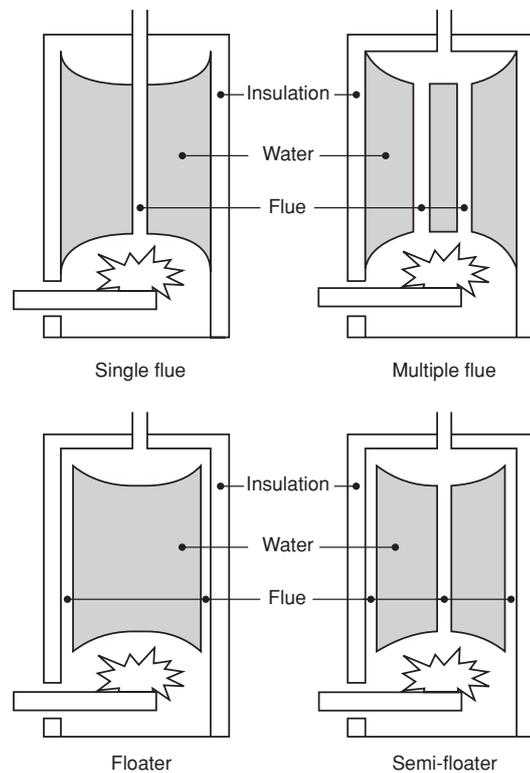


Figure 62: Types of primary flues

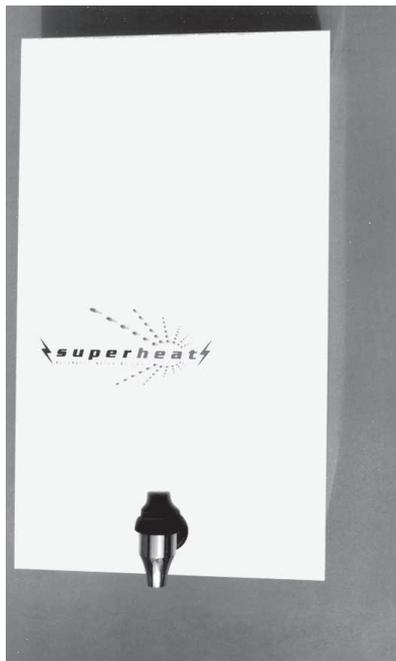


Figure 63: Wall mounted boiling water unit

### ***The relative energy efficiencies of gas and electric storage heaters***

In an electric storage heater the conversion of electrical energy to heat in the water is 100%. There are, however, standing losses from the cylinder which depend on the volume and the shape of the cylinder and on the quality of the insulation. In a modern (post-1988) “A grade” cylinder, the standing losses range from 1.5-2.5 kWh per day at normal operating temperatures.

The efficiency of conversion of the energy of gas combustion to hot water in a storage heater ranges from 70% to 85% with most designs giving 74% to 80% depending on the appliance. Because their insulation is not so good and because they need to have significant uninsulated areas (the heat transfer surface in the flue), standing losses in gas storage cylinders are quite high.

Gas cylinders are commonly mounted externally where they are exposed to lower temperatures than indoor mounted cylinders. Where a pilot flame is used about 50% of the energy of the pilot is lost up the flue.

A 135 litre gas storage heater loses in the region of 21 MJ/day (about 5.5 kWh/day), or about 3.5 times as much as an electric storage cylinder of similar delivery capability.

However, in comparing the energetics of electric heaters with gas heaters, one should take into account the source of the electricity. If the gas used for water heating would otherwise be used to generate electricity that is then delivered to the house and used to heat water, the overall efficiency of the process would be about 32%-50%. Direct use of the gas for water heating is therefore almost always more efficient.

### ***Life expectancy of cylinders***

The life of a hot water cylinder will depend on the material of which it is constructed, the quality of the water it is handling, and the usage to which it is subjected.

BRANZ estimate the probable lives of cylinders as shown in Figure 64.

### ***On-demand electric heating***

As was mentioned earlier, the main reason for using storage heaters is so that a moderate energy input over a long time can be used to provide a large energy output over a shorter time.

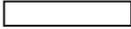
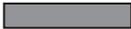
An alternative to storage heaters is the in-line or instantaneous heater, in which water is heated as it is needed. This requires an energy flux (power) matched to the instantaneous water flow and temperature. As was pointed out earlier, the low power input available in domestic wiring reduces the effectiveness of demand heating by electricity.

<b>Cylinder</b>	<b>Type</b>	<b>Usual Working Head</b>	<b>Life Expectancy</b>
copper	low pressure	2 - 7.6 m	20-50yrs
copper	low pressure	12.2 m	20-40yrs
glasslined steel	mains pressure	35-50 m	12-20yrs
stainless steel	mains pressure	35-50 m	20-40yrs (est)

Figure 64: Life expectancies of cylinder types

Flow rate (litres/minute) related to power input <sup>1</sup>				
Model size	Temperature rise /°C			
	25 Summer	30	35 Winter	40 Winter (cold regions)
3 kW	1.7	1.4	1.3	1.1
6 kW	3.1	2.8	2.5	2.1
7 kW	4.0	3.3	2.8	2.5
8 kW	4.5	3.8	3.2	2.8
10 kW	5.7	4.7	4.0	3.5
12 kW	6.8	5.7	4.9	4.2
14 kW	8.0	6.6	5.7	5.0
20 kW	11.4	9.5	8.1	7.1

<sup>1</sup> Based on 100% efficiency (in reality there are some small losses from the unit)

	unacceptable flow rates
	marginal flow rates
	satisfactory flow rates

**Figure 65: Flow performance from electric instantaneous water heaters**

The maximum power available to a single domestic circuit is usually about 3.6 kW although with special arrangements up to 8 kW can be made available. The maximum flow that can be heated to various temperatures from mains temperature and various power inputs is shown in Figure 65.

For hand washing a small 2-4 kW unit may be adequate. For showering, with a well-designed, low-flow shower head one can get by with 4 litres/min, but for higher temperature and higher-flow applications, such as clothes washing and dish washing, direct on-line heating is inadequate.

Many small domestic in-line electric water heaters operate at full power and the delivery temperature is controlled by adjusting the flow of water. There are, however, some very sophisticated units with built-in thermostats and flow meters which can deliver predetermined flows at predetermined temperatures. One of the simpler types is shown in Figure 66.

For industrial applications where very much larger (usually three-phase) power supplies are available on demand electric heating is feasible, but is usually delivered by purpose built devices.

Of particular interest in this respect is a recently developed unit “Transflux” which does not use conventional resistance heating and which can be built in compact form with high energy input and high hot water flows.

### On-demand gas heating

Gas has the advantage over electricity for in-line water heating in that it can provide much higher rates of energy input. Some domestic in-line water heaters can provide up to 50 kW input (185 MJ/hr) and many can provide up to 20 kW. The latter can provide flows up to 12 l/min at 40°C and 7 l/min at 60°C. Modern



**Figure 66: On-line electric device**



**Figure 67: On-demand gas water heater**

instantaneous gas heaters are equipped with control systems which allow the outlet temperature to be regulated and some are capable of supplying more than one outlet simultaneously.

## Energy losses

Energy can be lost from a hot water system in a number of ways:

- In transfer from the primary energy source to the water;
- in water expelled from the system by expansion during heating;
- in heat loss from the storage to the surroundings;
- in losses from pilot flames (e.g. in gas storage systems);
- in losses in the distribution system between the storage cylinder and the point of use;
- in losses from the system via leaking taps; and
- losses in pumps and controls (e.g. in systems with ring mains- see distribution).

Electrically heated systems in which the electric ele-

ment is immersed in the water in the cylinder have almost no loss in the transfer of energy from the element to the water. There are, however, standing losses incurred in maintaining the temperature of the stored water. Modern domestic gas storage systems, on the other hand, range between 70% and 80% efficient. Fully condensing systems can have efficiencies even higher than this.

## Expansion losses

Losses from water discharge resulting from thermal expansion vary with the type of system. Heating water from 10°C to 65°C involves an expansion of about 2%.

For a 270 litre cylinder this is about 5.5 litres.

Header tank systems have relatively small expansion losses because the expansion is taken up by movement of the coldest water back up the supply line from the header tank.

Pressure reducing valve systems with header pipes can lose up to several percent of the hot water produced through expansion into and overflow from the vent pipe. In some systems the level of the water in the vent pipe is maintained high to give an improved pressure leaving little space for expansion. This increases the expansion losses.

The situation is similar in earlier valve vented systems in which the only pressure relief is at the top of the cylinder.

Many modern valve vented systems have an additional expansion relief valve, known as a cold water expansion valve, at the bottom of the cylinder set to release water at slightly lower pressure than the safety valve. Thermal expansion is then dealt with by the release of cold water from below the element with very low energy loss. This eliminates a loss on average of about 80 kWh per year per household so equipped.

## Standing losses

These arise from heat transfer from the heated cylinder to the surroundings via the body of the cylinder and via the fittings (valves, pipes etc.) attached to the cylinder. A major determinant of heat loss from electric cylinders is the quality of the insulation. This has improved over the years and modern “A” grade cylinders have losses less than half of those of earlier cylinders.

Gas storage systems tend to have higher standing losses than electrically heated ones, largely because of the exposed area needed to achieve heat transfer from

the burning gas to the cylinder. Many of them have pilot lights which consume significant quantities of gas and while some of the pilot light energy goes to make up standing loss from the cylinder, the overall efficiency is lower on pilot than on heating mode.

Figures 68 and 69 show estimates of the standing losses from various storage types.

Type	kWh/year losses
Pre 1976	1500 - 2000
1976 - 1986 - 'C' Grade	1300 - 1800
'B' Grade - Open Vented	1000 - 1400
'B' Grade - Valve vented	850 - 1000
'A' Grade NZS 4605 : 1996	600 - 800

**Figure 68: Standing losses of electric storage systems**

Type	equivalent kWh/year losses
Pre 1980 - Open Vented	3500
2 - 2@star - Valve vented	2000 - 2200
External (3 star +)	1500 - 2500

**Figure 69: Standing losses of gas storage systems**

The use of an insulating blanket on older hot water cylinders can have a dramatic effect on the heat-loss, saving 1-1.5 kWh per day (350-550 kWh/yr) valued at about \$45-\$70 per year.

Instantaneous electric systems have overall thermal efficiencies of about 95%.

Instantaneous gas systems with automatic ignition have overall efficiencies about 65%-80%. Those with pilot lights can have significantly lower overall efficiencies, especially systems with low use in which the gas consumed by the pilot light becomes a major part of the total.

### Losses in distribution

One of the main causes of distribution loss is leaking taps and fittings. A hot water system with a tap which drips one drop per second will waste about 1500 litres of water per year and up to 100 kWh of electricity costing about \$14.

A second area of loss of energy is in long distribution

lines. A ten metre pipeline from a cylinder to a handbasin will take about 3 litres of hot water before any appears at the tap. This will approximately double the amount of water which is needed to rinse one's hands. If such a line is used six times per day at 2 hourly intervals (long enough for the water in the pipe to cool) the increase in water consumption over that actually needed will be about 18 litres per day or about 400 kWh/yr at a cost of around \$52/yr.

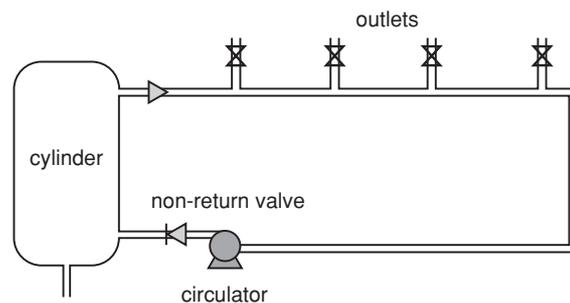
There are some differences of opinion about the merits of insulating long distribution lines. At one extreme, when the line is used frequently or continuously there is a clear advantage in insulating. At the other extreme when the line is used only very infrequently there can be a disadvantage when the energy required to heat the insulation is significant. In most domestic installations the advantage usually lies with insulation of the line.

In many commercial and some domestic systems the problem of time lag in getting hot water to distant outlets is overcome with a "ring main" in which hot water is continuously circulated with short side runs to the outlets. Insulation is clearly required in such a system.

Maintaining the temperature in a ring main from which only infrequent and small amounts of water are drawn can be wasteful of energy. In an attempt to reduce this waste, some domestic ring-main systems are controlled by a time clock, which ensures that the ring main is monitored only at times of frequent water use. Others use a thermostatic control which "refreshes" the ring main at intervals when the water in the coldest part has fallen to the lowest usable temperature.

### Local small capacity heaters

An alternative solution to the problem of remote outlets is to site a small storage heater close to the outlet with a capacity matched to the likely use. Where the flow and temperature required are both small it is also possible to use an instantaneous electric heater dedicated to the single outlet.



**Figure 70: Ring-main system**

# Chapter 7

## Management of Water Temperature

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### Temperature control

There are four aspects to temperature control in domestic hot water systems. These are:

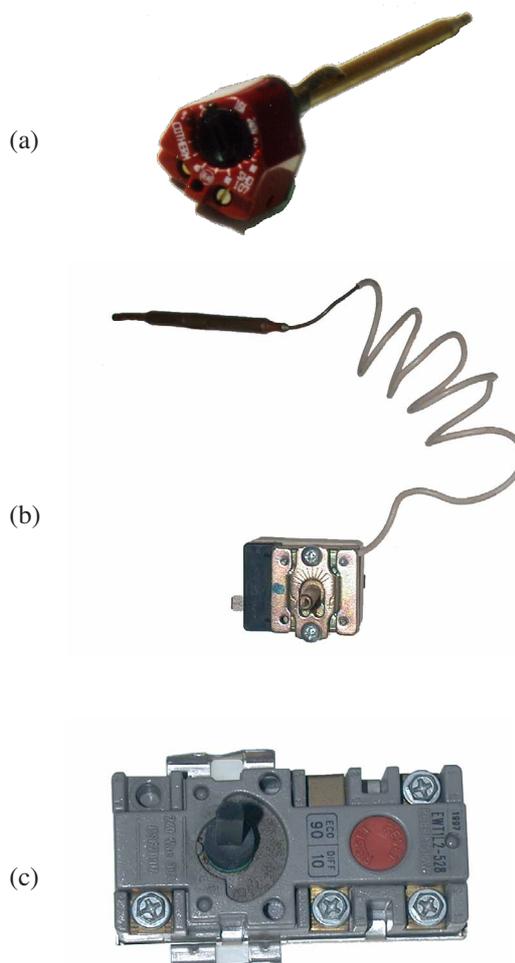
- maintenance of the set temperature of the stored water using thermostats;
- prevention of damage from extreme over-temperature (boiling and explosion), using over-temperature cut-outs and over-temperature relief valves;
- delivery of water at a safe temperature using tempering valves; and
- delivering water at an adjustable and comfortable temperature at the point of use. This is mainly of concern with showers where it is often achieved with a variety of arrangements of which the most sophisticated is a temperature controlling mixer valve. On baths, handbasins and sinks, the temperature of the final water is usually adjusted manually in a mixer tap in which the ratio of hot/cold water is set by the user or simply by running appropriate quantities of hot and cold water from separate taps. However, many kitchen and bathroom outlets are now fitted with single-lever mixing taps.

### Thermostats

A thermostat is a device which senses temperature and reacts at preset temperatures to turn a power supply on or off. Water heating thermostats are designed to regulate the supply of energy to the element and thereby maintain the water temperature within predetermined limits. This ensures that the temperature of the water is raised when fresh cold water is introduced to the cylinder and compensates for heat losses from the cylinder during long storage times.

The main types of thermostat used with hot water cylinders in New Zealand are:

- the rod type (Figure 71a);
- the consumer adjustable (capillary) type (Figure 71b); and
- surface mounted (Figure 71c).



**Figure 71: Thermostats (a) rod type, (b) consumer adjustable and (c) surface mounted**

The rod type thermostat is usually completely concealed within the element box and is not easily accessible to the householder. It is usually set during installation by the electrician and requires the removal of the cover plate and the use of a screwdriver to change the setting. Rod type thermostats appear in many older cylinders and are not noted for their accuracy.

The capillary type thermostat is now provided as standard with many new installations and can be readily fitted as a replacement for the rod type thermostat, even on old installations. Both rod and capillary thermostats have their sensors inserted in a tube projecting into the cylinder alongside the element.

Capillary thermostats are generally regarded as more accurate and more reliable than rod type thermostats. They usually have a control knob on the outside of the element box which can be adjusted in the range 50°C to 80°C. For this reason they are often referred to as “consumer adjustable” thermostats. Consumer adjustable thermostats have been promoted by the electrical industry and by energy conservation groups as a way of managing and saving energy in domestic hot water systems by adjusting the storage temperature to match the short term needs of the household. It should, however, be noted that an implication of the building code is that the thermostat should not be set below 60°C.

Capillary type thermostats are also used in the lock-out or “one shot” units fitted with quick recovery elements and as over-temperature protection devices. In both applications the thermostat opens the supply circuit permanently the first time the temperature exceeds the set value and must be reset manually before power is restored to the circuit.

Surface thermostats are mounted with their sensors in contact with the surface of the hot water cylinder inside the outer case. They can be either fully concealed or may have an externally adjustable control. Some surface thermostats have both normal thermostat and over-temperature protection capability within a single unit. When using surface mounted thermostats or servicing cylinders fitted with these units, it is important to ensure that the sensor makes good contact with the cylinder surface.

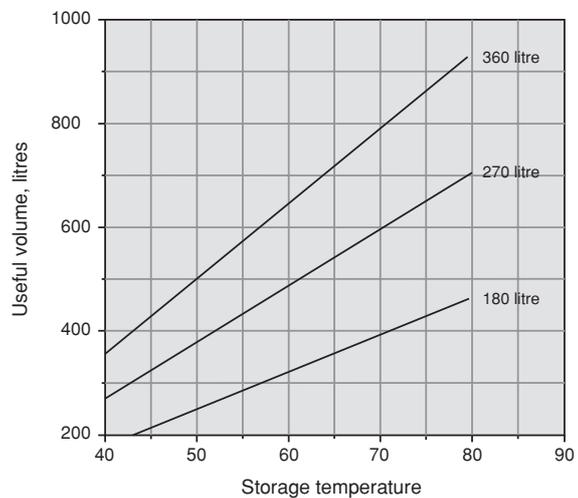
### ***Effect of storage temperature on useful hot water supply***

A consumer adjustable thermostat gives the user some degree of control over both the energy efficiency and the effective capacity of the hot water supply. For example, a 180 litre cylinder of water at 60°C will produce about 300 litres of water at 40°C. If the temperature of the cylinder is raised to 80°C then the same cylinder can produce about 450 litres of shower water at 40°C. This capability is useful in systems with undersized cylinders and when a temporary increase in capacity is required to provide for a short-term increase in demand, for example when a household has many guests.

In systems not fitted with tempering valves, increasing the storage temperature greatly increases the risk of scalding.

It is not advisable to keep the cylinder continuously at high temperatures because the standing losses will be higher.

The accuracy of thermostats can be affected by rough handling and poor installation and by deposits on the thermometer pockets in the cylinder. When system behaviour is being checked, it is advisable to note the temperature of the water delivered to the taps rather than to rely on the setting of the thermostat.



**Figure 72: Shower volumes vs storage temperature and cylinder volume**

### ***Primary supply control***

Many electricity supply companies offer several domestic tariff structures which are mainly relevant to water and space heating. Most such tariffs consist of a daily fixed charge and a variable energy charge or a pattern of energy charges.

Interruptible “ripple control” systems, in which the power supplier can remotely switch the power supply to the hot water system off at times of peak demand, were pioneered in New Zealand. About 93% of all domestic installations are under such control.

The three tariffs commonly offered are:

- uninterrupted supply, in which power is available to water heating equipment 24 hours a day;
- The “residential” option, in which power is usually available 24 hours a day, but may be interrupted at unspecified times by “ripple control”. This enables the power company to switch off certain circuits at will in order to control the overall load; and
- Off-peak rates, usually ones in which power is available to water heating (and sometimes other circuits) only during the low-load night time period. The hours during which night-rate power is available can vary and different rates apply to the various choices. Some power companies offer lim-

ited supply to the hot water cylinder during the night with a “boost” supply during the afternoon.

It is not possible in this book to summarise all the various arrangements, but we shall use one particular structure as an example. It should be emphasised that the actual numbers used in this example are specific to a particular company and time. The basic principle of the calculation is, however, general.

### Uninterruptible

The first rate is applicable to residential customers where the company does not control any part of the load.

(A)	daily fixed charge	37.496 cents
	energy	18 cents/kWh

### Ripple Control

The next rate is for electricity supply in which the supply to the water heater is ripple controlled by the supply company and can be switched off by the company as part of its load control strategy.

(B)	daily fixed charge	37.496 cents/day
	energy supply	13.714 cent/kWh

The lower rate recognises the advantages to the power supply company of being able to partially control its load.

### Night Rate

Night rate options supply electricity to certain appliances such as hot water cylinders only during the night hours when other load is low. About 7% of New Zealand hot water systems use night-rate tariffs.

Some companies offer a range of night rate options in which the rates depend on the hours for which water heating power is available. Some also offer a boost during the afternoon.

This example considers one in which power is available for water heating (and in some cases other appliances such as space heating storage devices) only from 11 pm to 7 am. This has three components:

(C)	daily fixed charge	37.496 cents
	daytime electricity (7am to 11 pm)	16.396 cents/kWh
	night time electricity (11 pm to 7 am)	5.423 cents/kWh

It should be noted that the daytime rate is higher than

the “ripple only rate” and the night time rate is much lower.

In the example given above there is a net saving if the energy used in the night period exceeds 24.26 % of the total energy consumed. If the total energy is less than this the night rate tariff (C) is overall more expensive than the ripple only tariff (B). On the other hand, the saving starts at 24.26% and increases as the proportion of load that can be transferred to night rate increases beyond this value. In a typical household, in which 35% to 40% of electricity use is for water heating, the night rate option will be advantageous. However, if an electricity saving option such as a wetback, solar heater or heat pump is introduced this may tip the scales in the other direction such that the lower night rate is more than offset by the higher day rate.

These calculations show that if a significant fraction of the total load lies in the night rate time, then cost savings can be made that compensate for any inconvenience which is incurred by having a limited supply.

It is important to evaluate the potential savings in terms of the total annual energy use of the household.

The decision must be made on the basis of an electricity consumption analysis for the individual household and should include all the night use appliance options.

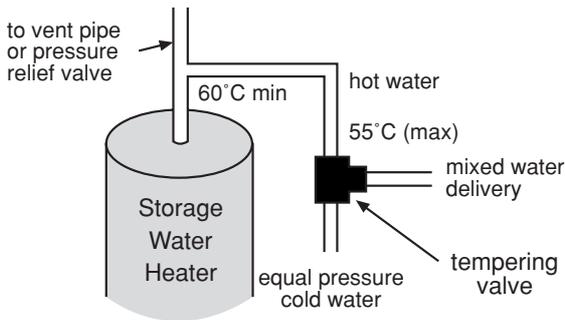
In order to take advantage of night rate water heating without significant inconvenience, it is usually necessary to have both a cylinder capable of supplying the expected hot water requirements of the household for a whole day and an element capable of heating that water to the required temperature in the available night-rate time. This in turn requires an analysis of the household water use.

For example, in a six person household one might expect to use 250-350 litres of hot water (60°C) per day mostly between 7 am and 11 pm. It would therefore be advisable to have, say, a 360 litre cylinder. Assuming that there are days on which the cylinder has been fully used by 11 pm then one needs to reheat the cylinder in the 8 hours of night rate electricity supply. If the mains water supply is at 10°C this will require 21 kWh to which needs to be added the expected storage loss of about 2 kWh. The minimum element power required is thus 3 kW.

## Tempering Valves

Another form of temperature control, which is becoming more common and is used to comply with the building code requirements on new installations, is the tempering valve.

The tempering valve is designed to mix cold water into a hot water flow so ensuring that the water delivered from the cylinder to the taps never exceeds a specified value, as shown in Figure 73. The tempering valve senses the temperature of the water coming from the cylinder and if it exceeds the set value the valve mixes in cold water to bring the temperature of the delivered water down. If the water from the cylinder is below the set temperature of the tempering valve then no cold water is added.



**Figure 73: Tempered water delivery**

The Building Code requires that the water delivered to sanitary fixtures used for personal hygiene purposes shall not exceed 55°C.

The water supply to kitchens and laundries is not required to be tempered and dual temperature supply can be achieved by the arrangement shown in Figure 74.

The use of tempering valves ensures the safety of hot water users independently of the storage temperature.

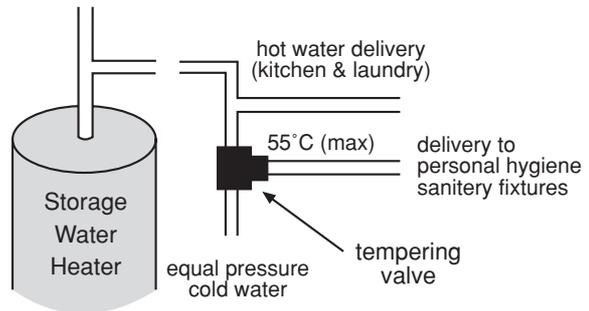
Some early models of tempering valve caused problems, particularly in low pressure hot water systems, by restricting the flow to showers. There are now available tempering valves which can operate effectively

down to pressures corresponding to as little as 1.5 m head.

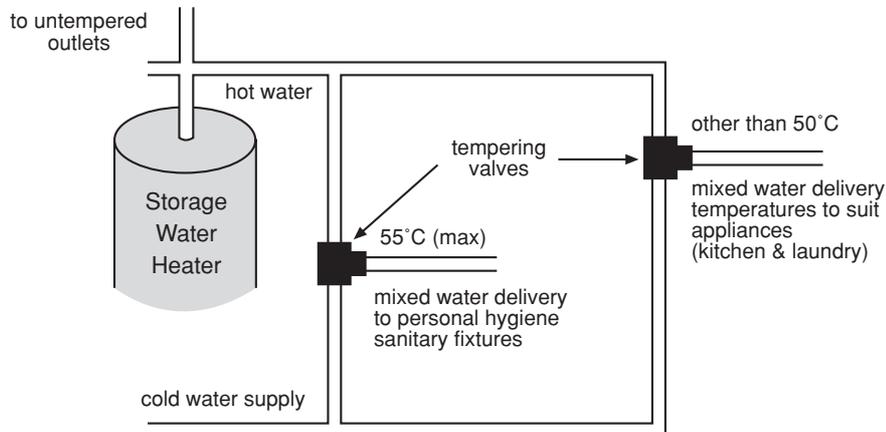
Some shower mixer valves (see Delivery Systems, Chapter 9) are designed to work with input of hot water at 70°C to 77°C and are unable to perform satisfactorily with 55°C water. Many shower mixer taps are designed to operate with equal hot water and cold water pressures, but there is at least one which can handle low pressure hot water and high pressure cold water inputs.

Most tempering valves are designed to work with equal pressure hot and cold supplies and care must be taken to ensure that, where required, this condition is met.

Common installation practice is to fit the tempering valve so that the supply to all outlets in the house is tempered. A proposed revision of the Building Code is to alter the tempering temperature to 50°C, which may be regarded as too cool for kitchen uses such as dishwashing. This may necessitate a more general change to the layout shown in Figure 74 or to more elaborate layouts like that shown in Figure 75, which shows a system with two separate supplies tempered to different temperatures.



**Figure 74: Selective tempered water delivery**



**Figure 75: Tempered water delivery to all outlets**

# Chapter 8

## Alternative Energy Sources for Water Heating

So far discussion has been confined to systems using gas and electricity. There are, however, a number of other ways in which water can be heated, and these are discussed in the following sections.

The distribution of energy sources among a sample of hot water systems surveyed recently by BRANZ is shown in Figure 76. Figure 76a refers to the North Island, where gas is reticulated, and Figure 76b refers to the South Island where hot water systems are almost exclusively electric.

### Solid fuel devices

#### Wetbacks

For many years electrical heating of water was augmented by solid fuel combustion in “wetback” attachments to coal-fired cooking ranges, open fires and so-called waste destructors or chip heaters. In the early versions the fire was partly surrounded by a water jacket which acted as a heat exchanger and the heated water circulated through the cylinder by convection as illustrated in Figure 77.

In more modern equipment the water circulates through a tubular heat-exchanger exposed to the fire or to the hot combustion gases in the flue.

Almost all wetback systems operate in a thermosyphon mode, relying on the density difference between the hot water in the wetback itself and the density in the

cylinder to cause the water to circulate. For this reason the cylinder is normally sited higher than the heat source (fireplace or log burner).

The efficacy of these devices varies with their design

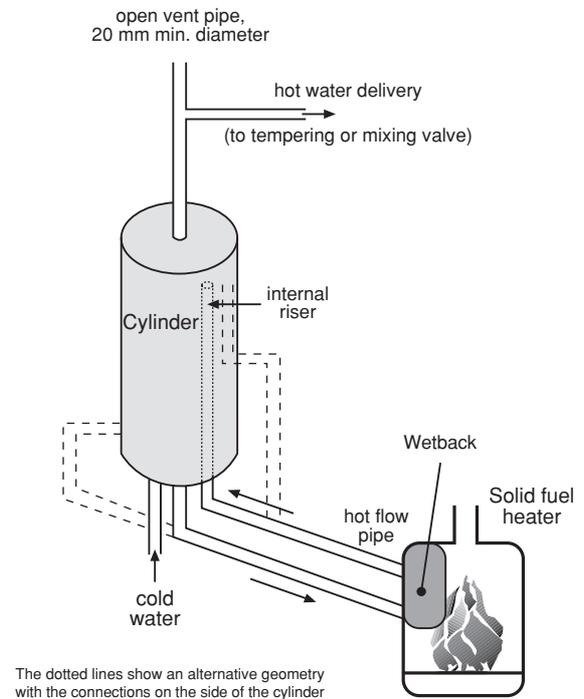


Figure 77: Conventional wetback

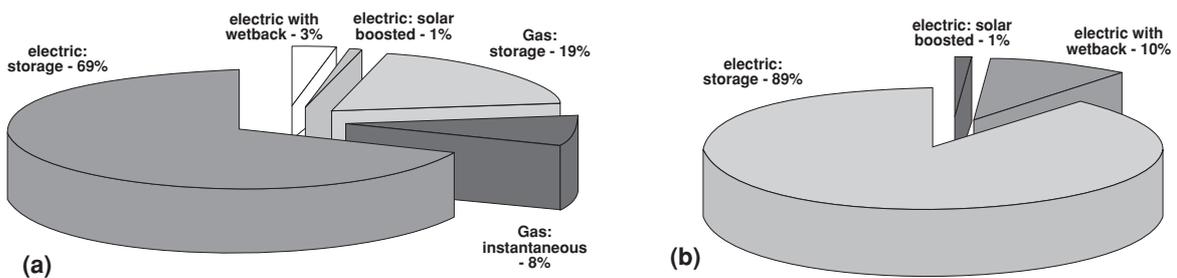


Figure 76: Distribution of energy sources for hot water systems: (a) North Island and (b) South Island



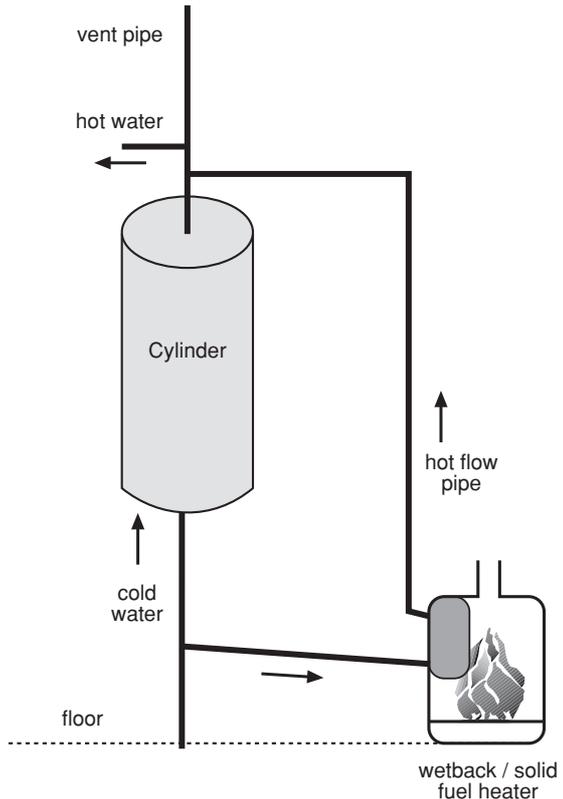
**Figure 78: Wet back heat exchanger**

and with the position of the heat exchanger in the combustion system. Figures ranging from 500 W to 5000 W are quoted by manufacturers for the input from wetbacks to the hot water system. Many of the wetback heat exchangers appear to have had no precise measurements made on them. Because these items are thermosyphons it is important to get the geometry of the pipe-work correct.

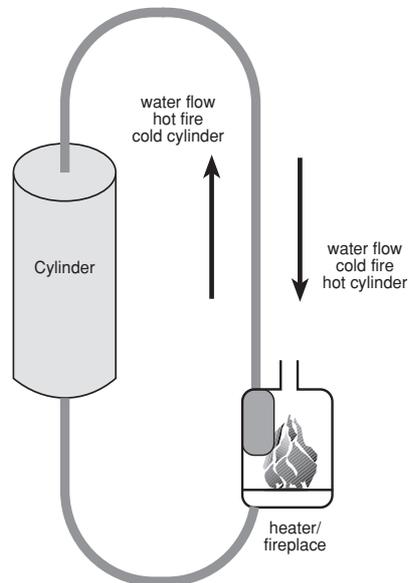
In general, the bottom of the cylinder should be above the top of the wetback and pipes between the wetback and the cylinder should have a gradient averaging more than one in seven. Care needs to be taken to ensure that there are no loops to trap air which comes out of solution in the water as it is heated. This usually means that the cylinder is placed close to and slightly above the stove or log burner. Cold water flows from the bottom of the cylinder to the bottom of the wetback and from the top of the wetback to the return point in the cylinder. The return to the cylinder usually has an internal riser so that the hot water from the wetback is returned high in the cylinder giving it a degree of quick recovery.

It is inadvisable to return hot water directly to the top of the cylinder as shown in Figure 79(a), as this will allow back-circulation of water from the cylinder to the wetback when the fire is not lit, allowing energy to be wasted. A system set up in this way would behave as a simple loop with heating on one side when the fire is burning, but with heating on the other side when the cylinder is hot and the fire is not lit (see Figure 79(b)). Moreover this system can run the risk of having water boil in the wetback and escape directly via the vent pipe as a mixed steam and water flow.

Despite these constraints some quite unusual wetback



**Figure 79(a): Layout allowing back circulation of water from cylinder to wetback**



**Figure 79(b): Water circulation based on layout in Figure 79(a)**

arrangements have been built which appear to work quite well. One such is the “over and under” layout in which the cold line from cylinder to wetback goes under the floor and the hot flow is taken over the ceiling and back to the cylinder as shown in Figure 80.

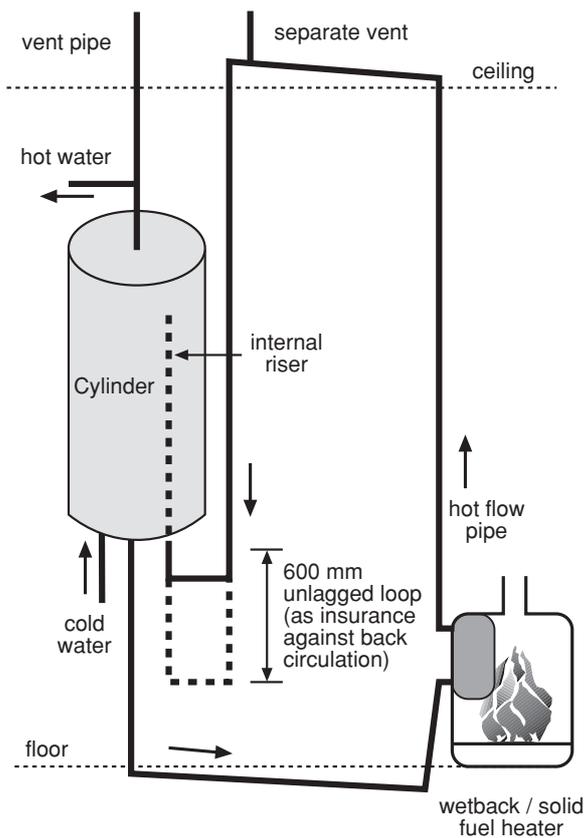


Figure 80: Over and under wetback

**Pump circulated wetbacks**

In some circumstances where a simple thermosyphon arrangement is not applicable a pump can be used to circulate water between wetback and hot water cylinder. The pump is usually controlled by temperature sensors in the outlet from the wetback and the cylinder. Both the performance and the safety of such systems are dependent on the reliability of the pump and the control system. The technical complication of such systems and their cost have tended to make them uncommon.

**Self pumping wetbacks**

The requirements of the natural convection systems such as limitation on geometry and pipe lengths can be overcome with self pumping or “pulse flow” circulators such as the “HITEMP” system.

**Venting of wetbacks**

All wetback systems are required by law to be open vented to atmosphere and are thus limited to atmospheric pressure. In a system in which the water circulation is direct from the hot water cylinder to the wetback this limits the operating pressure of the hot water system itself.

This limitation can be overcome by using a low pressure coil in a higher pressure cylinder as shown in Figures 81 and 82.

Such a system usually requires some means of maintaining the water supply to the wetback loop. This can be achieved by the use of a small header tank and ballcock as in Figure 81, or by the use of a pressure reducing valve as shown in Figure 82.

Because of its mode of operation (thermosyphon heated by fire) the conventional wetback is capable of producing water delivery temperatures far exceeding the thermostat setting and which can be up to 100°C. As a result the risk of scalding with systems using wetbacks is increased. For this reason it is important to retrofit tempering valves to cylinders with wetbacks wherever possible. Care should be taken to select a tempering valve which works well with low pressure water supplies.

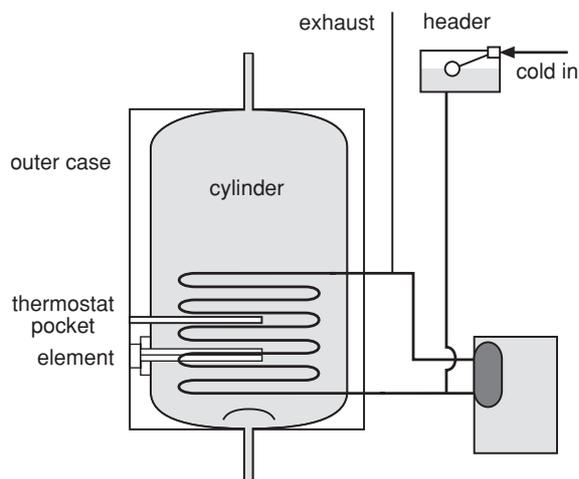


Figure 81: Header tank

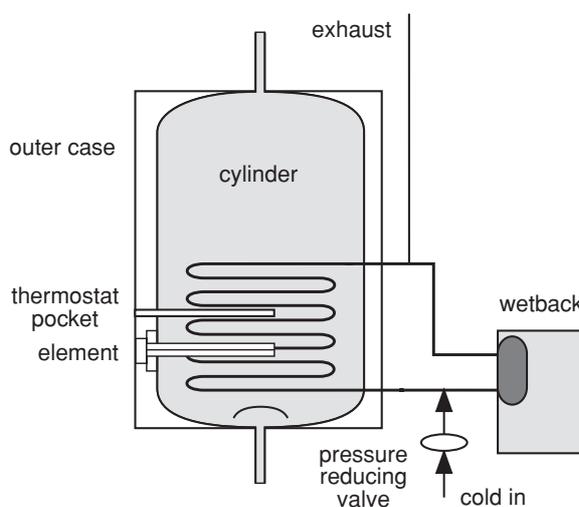


Figure 82 : Pressure reducing valve

### Choosing a wetback

As was mentioned earlier, wetback fittings come in a wide range of performance levels. Although some can be fitted to several different burners, most are designed for specific burners and are ordered at the time the burner is installed.

Care should also be taken to ensure that the burner meets the local emission standards *with the wetback fitted*.

Outputs of wetbacks are usually quoted for high burn rates in the burner and sometimes even at maximum burn rate.

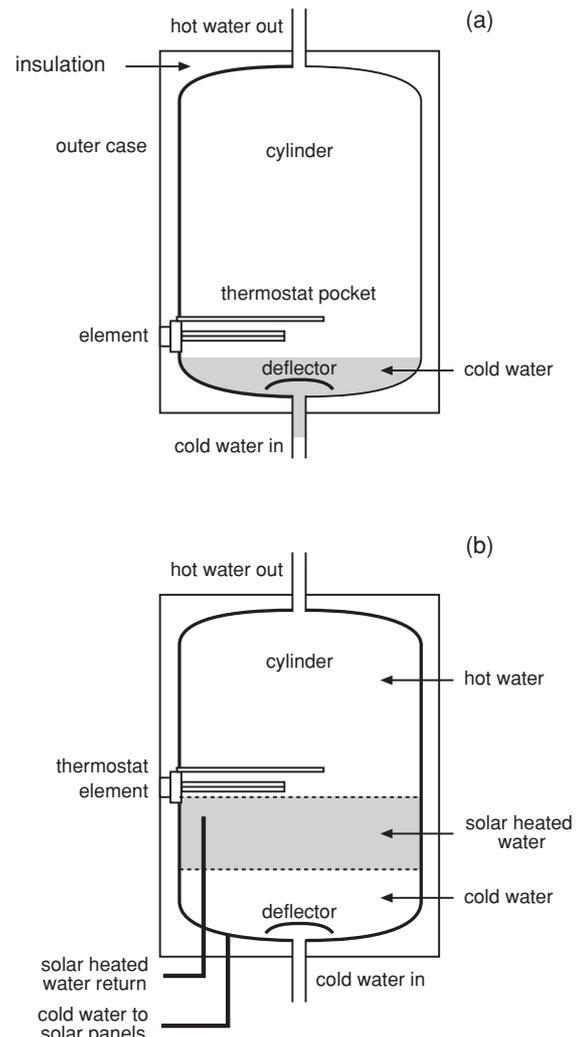
In choosing a burner and wetback combination they should be matched to the likely burner operating conditions (time, burn rate and output) and likely water requirement. Otherwise a gross undersupply or oversupply of hot water can result.

### Solar water heating

The sun is a quite useful source of energy for water heating. Its intensity reaches 1 kW per square metre on a bright day and it is therefore necessary to have only a few square metres of collector to provide a worthwhile input. The main defect of the sun as a source is that it is intermittent on a daily basis and highly variable on a seasonal basis and one cannot therefore rely on it for 100% of the energy needed. For this reason solar water heating is usually installed as part of a storage system and is usually augmented by some other energy source.

Solar water heaters are storage water heaters having an insulated storage tank connected to solar collectors which absorb the sun's energy and transfer it to the water. The storage tank usually includes an electric element and thermostat to boost and control the water temperature during periods of low insolation. Like the wetback a solar water heater is "uncontrolled" though it is to some extent self regulating and generally not capable of the continued high inputs of the wetback. For this reason solar-booster systems must also be fitted with tempering valves.

In New Zealand the most common combinations are solar/electric and solar/electric/wetback. A solar water heating system consists essentially of an absorber ("collector") that absorbs the solar radiation and heats water, and a means of circulating the heated water in the storage cylinder. The cylinder configuration in a solar electric system with a vented cylinder is usually slightly different from a standard cylinder, as shown in Figure 83. The element is part-way up the cylinder (usually a third to a half) and the solar heated water is



**Figure 83: Difference between (a) standard cylinder and (b) solar cylinder**

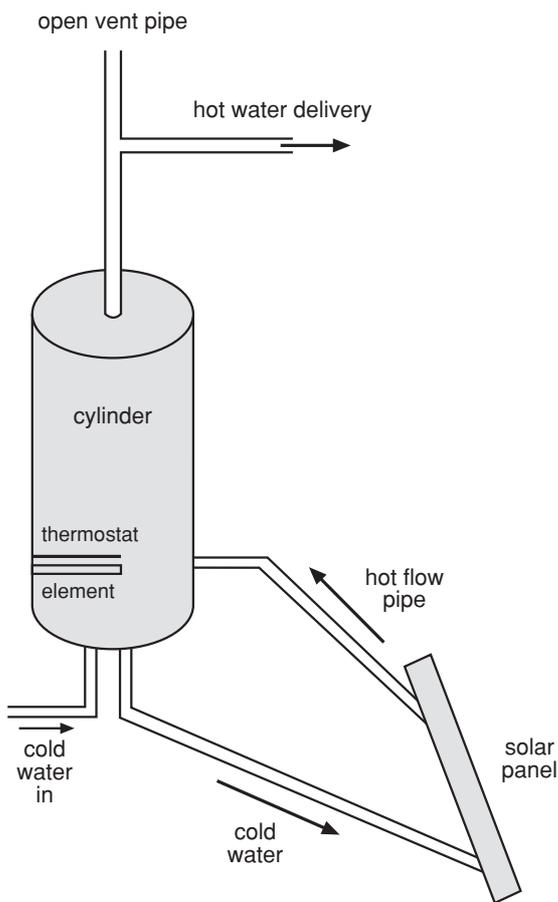
circulated in the lower section below the element. This ensures that the water is always heated as much as possible by the solar panel before being exposed to the electrical heating system.

There are two main types of solar water heating system, namely thermosyphon and pump circulated. The thermosyphon system relies on convection to circulate water through a solar panel and back to the cylinder as shown in Figure 84.

This type of system has the advantage that it is simple and requires no additional mechanical or electrical devices.

Its main disadvantage is that it needs to be set up very carefully to ensure that the thermosyphon action is reliable.

Firstly, because the thermosyphon effect provides only



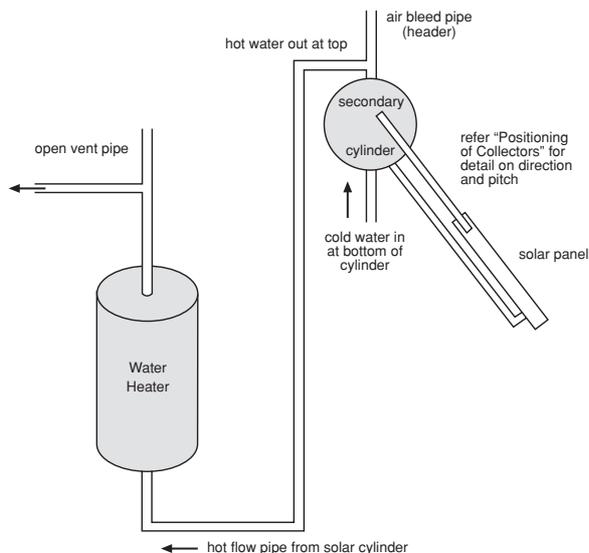
**Figure 84: Thermosyphon solar collector**

a very small driving head for the circulation, the cylinder must be above the solar collector panels so that there is enough rise in the system for the thermosyphon to work effectively. Secondly, the pipework should have a continuous rise between the panel and the cylinder to ensure that any air which happens to be released in the pipes can find its way back to the cylinder. If this is not done there is a danger that the air will collect in the high point of the pipe-run and the thermosyphon action will cease. Thermosyphon systems use quite large bore piping so as to reduce the resistance to flow.

**Dual cylinder thermosyphon system**

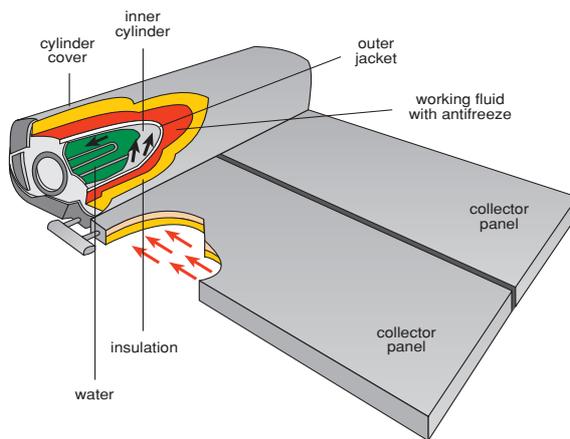
In some cases it is convenient to use two cylinders, one in the roof space above the cylinder, and the second, conventional electrically heated cylinder, in a “normal” hot water cylinder cupboard. In this arrangement the solar collector circulates water to the upper cylinder which acts as the feed of pre-heated water to the electrically boosted cylinder as shown in Figure 85.

A particularly compact form of thermosyphon system uses a close coupled cylinder/panel arrangement such as that shown in Figure 86 with the cylinder placed



**Figure 85: Dual cylinder system**

horizontally directly above the panel. In some forms of this arrangement the element is also placed in the cylinder thus eliminating the need for a second cylinder.



**Figure 86: Close-coupled thermosyphon with double-jacket cylinder (Solahart)**

**Frost protection of thermosyphon systems**

In frost prone areas some protection against freezing of the panels and waterways must be provided. This is frequently done with a “frost” valve which is designed to open and let a small flow of warmer water from the cylinder trickle out through the collector to waste when the temperature gets dangerously low. This ensures that the panel does not freeze. The price of this type of protection is the loss of some warm water from the cylinder. There is also the possibility that the frost valve can be held open by grit in the water supply and go on discharging water after the frost danger has passed.

An alternative approach that is sometimes adopted is to have a low wattage electric heater built into the back of the solar panel and operated by a thermostat, so that when freezing conditions are approached the heater comes on and prevents the panel from getting too cold.

Another approach to frost protection is to build in to the solar panel a tube filled with non-freezing fluid which can be displaced thus allowing for the expansion of the water that occurs on freezing.

Some thermosyphon systems use a heat exchanger between the fluid circulating in the collector and the water in the cylinder. This enables the use of an antifreeze in the collector which is chosen so that its freezing point is below the lowest temperature likely to be encountered in the region. In some designs of close-coupled thermosyphon systems, the primary (antifreeze) circulating fluid flows between the panel and a jacket round the outside of the hot water cylinder proper as shown in Figure 86.

The final approach to protection is simply to drain the panels and associated piping and to forego the small amount of solar gain during the winter or freezing season.

### Pump Circulation

In a pump circulated system as shown in Figure 87, the water flow in the collector panels is generated by a small pump which is turned on and off by a controller which senses the temperatures of the collector panel, and of the storage cylinder. When the collector panels are hotter than the cylinder the pump is turned on and circulation continues until the temperature difference between the panels and the cylinder falls to some smaller preset value.

The advantage of a pumped system is that no fixed relationship is required between the positions of the cylinder and the collectors. When a pump circulates the water between the collector and the cylinder the relative height of the cylinder and the length of the pipes becomes less significant, although a large distance between the cylinder and the collector can contribute to inefficiency and there is still a possibility of air locks in high loops of piping, which the pump must be capable of overcoming. The disadvantage is that the system requires additional equipment in the form of a pump and a control system. The control system which actuates the pump for energy collection can also act as a frost protection device by sensing the panel temperature and circulating water through the panels from the cylinder when the panel temperature becomes dangerously low. In the pump circulated system the water flow used for frost protection returns to the cylinder and does not go to waste.

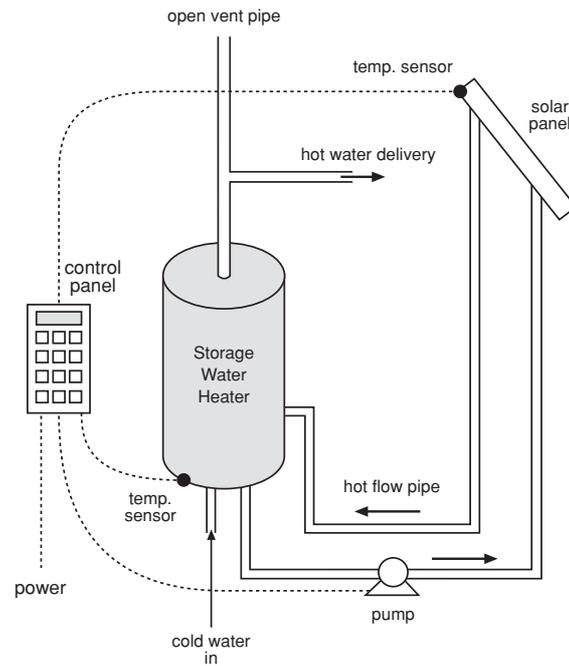


Figure 87: Pump circulated system

Pump circulated systems may also be set up with heat exchangers so that the fluid circulating in the collectors can be inherently freeze-proof. This is usually achieved by putting a heat exchanger coil in the hot water cylinder as shown in Figure 88.

The circulating fluid in the primary loop is usually a mixture of water and propylene glycol which is non-toxic. Nevertheless the primary fluid is usually brightly coloured so that if any leakage does occur between the primary and the secondary circuits it will be readily noticed.

### Collectors

The collector is that part of the system which absorbs

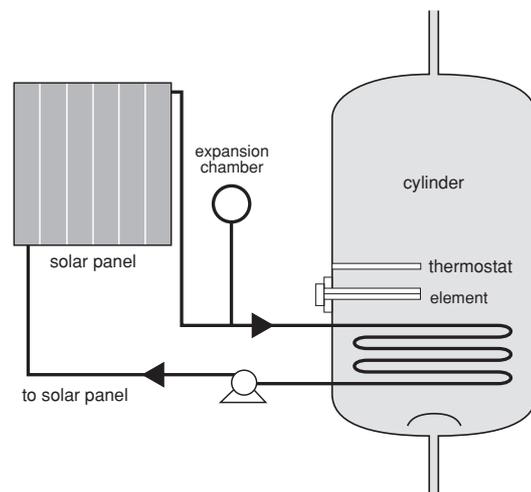


Figure 88: Two-stage pump circulated system

the sunlight, converts it into heat and transmits the heat to the water. Almost all domestic solar water heating systems are flat-plate collectors with fixed orientation. Solar collector panels are obviously at their best when pointing towards the sun.

The ideal orientation for fixed flat-plate collectors is to have the panels pointing due North (geographical North *not* magnetic North) and at an inclination to the horizontal equal to the latitude. This gives the best overall energy collection when averaged over the whole year. Minor deviations from this optimum, as shown in Figure 89, do not have a major effect on the total energy collection. Changes in the angle of inclination will however affect the seasonal behaviour of the collectors.

The optimum angle given above will give a greater collected energy in the summer than in the winter. Lowering the angle will emphasise the summer collection even further at the expense of the winter collection. Raising the angle will improve the winter collection, while reducing the summer collection. Summer daily performance will reach a maximum at around an angle equal to latitude -23 degrees and winter performance

will be maximised at latitude +23 degrees though at these angles total annual performance will begin to suffer. In systems where solar collectors are combined with wetbacks there is an advantage in setting the solar panels at the flatter angles to emphasise summer performance because the winter water heating will come largely from the wetback.

**Siting of collectors**

There are a variety of ways in which the collectors can be mounted to the building. Close-coupled thermosyphons of the type shown in Figure 86 are usually mounted directly on to the roof. Separate panels can be mounted on a frame on the roof, either directly, as shown in Figure 90, or integrated with the roof, as shown in Figure 91.

When the roof surface does not face in the NE to NW quadrant, or is flatter than about 20°, solar panels are often mounted on frames which stand off from the roof.

**Collector types**

The most common type of collector is the “flat-plate tube-on-sheet collector” shown in Figures 92 and 93.

Orientation E-W		Inclination Angle					Vertical 90°
		Flat 0°	20°	40°	60°	80°	
West	270°	Not allowed	1.18	1.25	1.39	1.67	1.88
	300°		1.09	1.09	1.16	1.37	1.54
	330°		1.02	1.01	1.04	1.25	1.41
North	0°		1.03	1.00	1.06	1.25	1.43
	30°		1.06	1.05	1.14	1.35	1.54
	60°		1.14	1.16	1.30	1.54	1.75
East	90°	1.25	1.37	1.56	1.92	2.17	

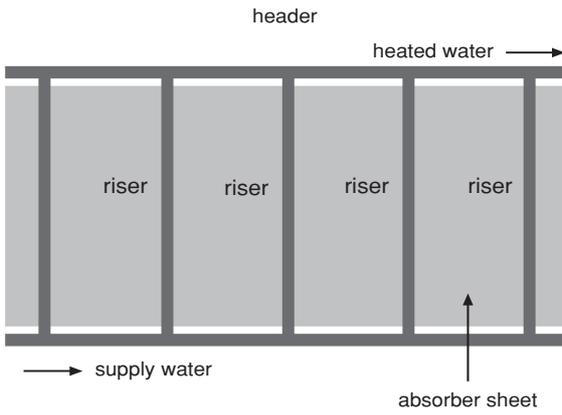
Figure 89: Relative areas of collector to achieve a given performance



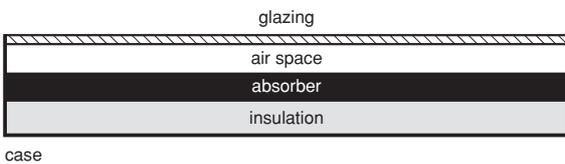
Figure 90: Roof-mounted collector



Figure 91: Roof-integrated collector



**Figure 92: Tube on sheet absorber**



**Figure 93: Flat plate collector cross-section**

Heat absorbed by the flat plate is conducted to water that flows in the risers running between a supply and a return header. One of the advantages of the flat plate collector is that it can be quite effective over a wide range of angles of incident radiation and can therefore be used at a fixed inclination and orientation.

The optimum orientation for a flat-plate collector is pointing north and tilted from horizontal at the latitude angle.

However, quite wide deviations from this orientation are permissible, as shown in Figure 89, which shows the relative areas of collector required to provide a given performance at different orientations and inclination. Thus at latitude 40° south, an array pointing north-west at an inclination of 40° would give about 7% less overall than one pointing due north.

The absorber is placed in a weather-proof case with insulation behind the absorber and a transparent (glass or plastic) cover in front.

The performance of the flat plate collector depends on the intensity of the solar radiation (insolation), the operating temperature of the panel, the ambient temperature and the general construction of the panel. The latter includes such factors as the transmission of radiation by the cover, the absorptivity and thermal conductivity of the sheet, the quality of the insulation and the spacing of the risers.

The design of an economically viable collector in-

volves compromises among these factors but in general the overall performances of commercially available collectors are fairly similar.

The efficiency of a flat plate collector can be described by the Hottel-Whillier-Bliss relation shown in Figure 94.

In this figure, the efficiency is the fraction of the solar energy falling on the panel which is converted into hot water,  $I$  is the intensity of the solar illumination (in watts per square metre) and  $\Delta T$  is the difference in temperature between the panel and the ambient air. In the example shown in Figure 94, the maximum efficiency is in the range 70% to 75% when ambient temperature water flows in the panel and falls off as the water temperature rises.

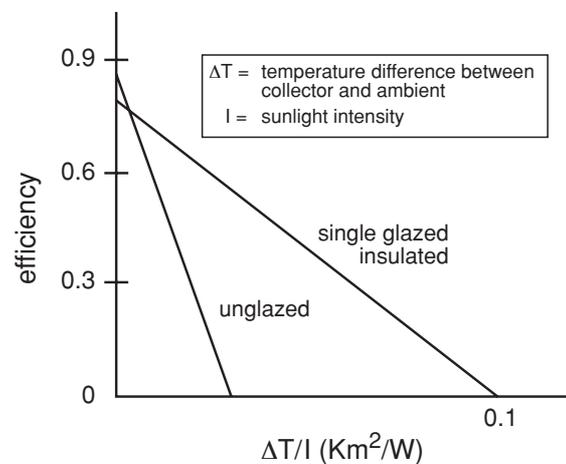
The overall daily effectiveness is usually about 30%-40% of the total solar input. However this can vary greatly according to the way the system is set up and from day to day.

### Swimming pool heating

As can be seen from Figure 94, when the system is operating only a few degrees above ambient as is the case with a swimming pool heater then poor insulation and lack of glazing do not seriously affect the performance. For this reason it is possible to make quite simple and cheap solar swimming pool heating equipment using methods and materials which would be unsuitable for domestic water heating. The presence of pool water treatment chemicals can however limit the use of some materials.

### Panel designs

The simplest tube-on-sheet panels were made of cop-



**Figure 94: Hottel-Whillier-Bliss relation**  
Values shown are typical

per sheet with copper tube risers usually soldered to the sheet. Over the years, by both experiment and theoretical calculation, the layout of such panels became optimised with respect to the spacing of the risers (about 150 mm) and the thickness of the sheet (about 0.5 mm) so as to produce the best performance for the amount of copper used. Initially the absorbing surface was a simple matt-black paint or oxidised copper surface.

With the increasing cost of copper, various attempts have been made to achieve good performance with reduced amounts of copper and with the use of cheaper materials. The most common method is to replace the copper sheet with aluminium which has a thermal conductivity about half that of copper. This is offset by using thicker sheet or closer spacing of the risers. A problem with aluminium sheet and copper tubing is making a good thermal bond between the sheet and the tube.

A specialised material (“Tecknoterm”) which solves both problems uses thin copper and aluminium sheets roll-bonded together so that the copper is welded to the aluminium and the copper section is then hydraulically expanded into a tube with the aluminium forming fins along the tube (see Figure 95). The lower conductivity of the aluminium sheet is compensated by a “selective” coating which ensures that the aluminium surface operates at a higher temperature than would a matt black surface. This material is used in New Zealand in “Sola 60” and “Solar Solutions” collectors.

A quite different approach uses the heat pipe effect to

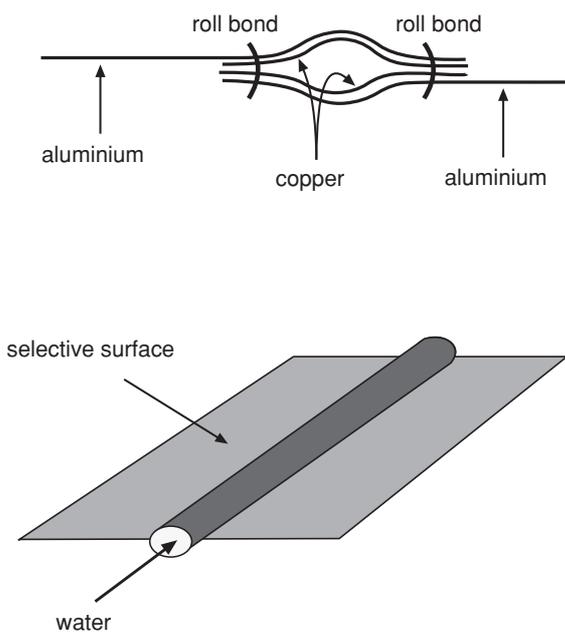


Figure 95 : Tecknoterm

achieve a very high thermal conductivity that is nearly independent of the material used. A heat pipe in its simplest form is a tube from which air has been removed and into which a small quantity of volatile liquid has been introduced. Such a device conducts by evaporation and condensation of the working fluid and has an effective thermal conductivity a thousand or more times that of copper. A flat plate version of a heat pipe made from steel sheet is used in “Thermocell” collectors. Because of the extremely high conductivity of the flat plate heat pipe it is necessary to have a horizontal “riser” along the top edge of the panel only and no headers, as shown in Figure 96.

An alternative approach to the use of steel in a flat plate collector has been developed in the Solahart collector in which a double-walled steel flat plate containing water loaded with antifreeze and corrosion inhibitors is connected as a close-coupled thermosyphon to the outer shell of a double jacketed water cylinder as shown in Figure 86.

### Special hot water cylinders for solar systems

The hot water cylinder plays a significant part in the overall performance of a solar boosted hot water system. Because water may be heated at a time different from its use, it is important to have a well-insulated cylinder that will allow water to be stored effectively for longer periods. Again, because the sun is an intermittent source of energy, it is advantageous to have a cylinder that is somewhat larger than would otherwise be chosen. However the match between cylinder size and panel area should be made so as to ensure both a reasonable quantity of heated water and a reasonable temperature.

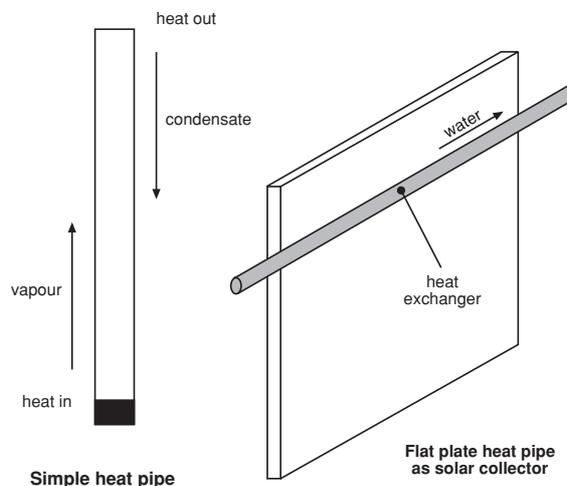


Figure 96: Thermocell panel

Because of the intermittent and seasonal nature of solar input it is generally not economic to build a system that can cope with 100% of a household's hot water needs for the whole year. Such a system would grossly over-perform at times of good insolation. Normally solar water heating systems in New Zealand are sized to supply between 50% and 75% of the hot water energy for the year.

In systems with both solar and electrical input it is desirable to minimise the competition between the two energy sources. One way of doing this is to have a two tank system in which the solar energy is used to heat water in a primary cylinder from which water is drawn to a secondary electrically heated cylinder where it is further heated if necessary to a controlled temperature as shown in Figures 85 and 97.

The two tank system is often found in thermosyphon systems, particularly those retrofitted in houses already equipped with conventional hot water cylinders.

The use of two cylinders introduces some characteristics which are less desirable. For example if the power supply in the secondary cylinder is off and there is ample sunshine, but water is not drawn from the system for some time, one can finish up with very hot water in the primary cylinder and cool water in the secondary cylinder which must be drawn before the hot water can be accessed. This in turn can be avoided by having a bypass arrangement which allows water to be drawn directly from the primary system. The two tank system can be expensive and can require careful management to achieve optimum performance. In its simplest form it introduces some loss of efficiency in the form of heat losses from the additional cylinder. Several arrangements using only one cylinder have been implemented.

One such approach is to ensure either manually or with

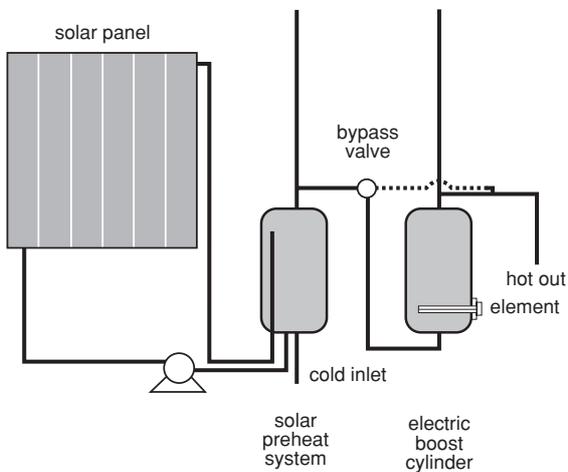


Figure 97: Two tank system

a time switch that the electric supply is interrupted during daylight hours. This produces virtual “night rate” operating conditions with electrical backup available on days without sunshine. Manual operation of the control on the electricity supply is effective, but requires vigilance and recognition of the weather conditions by the operator.

A compromise situation can be achieved by having a two-stage cylinder shown in Figure 98.

In this arrangement cold water entering the cylinder is exposed first to the solar system and is returned to the cylinder just below the element. If the returned water is below thermostat temperature there is a stratification line at the thermostat and a second one which moves down from the element as the solar heated section builds up. Eventually, in sunny conditions, the temperature of the solar heated water exceeds thermostat temperature and the returning water convects upwards into the upper region raising the temperature of the whole cylinder above the thermostat temperature. When water is drawn from the top of the cylinder, cold water enters the bottom of the cylinder and the system behaviour reverts to the initial mode.

The exact proportions of the cylinder volume above and below the element vary with the size of the cylinder, the expected hot water use pattern and the manu-

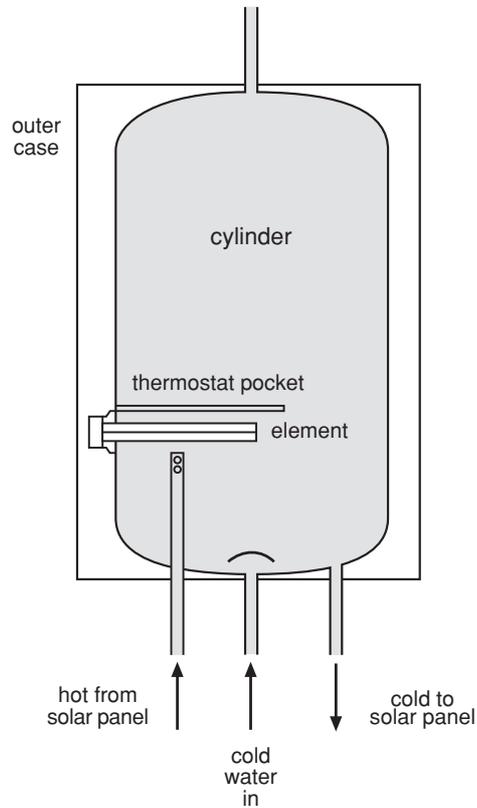


Figure 98: Solar cylinder

fracture of the cylinder. It is common in two-stage cylinders to find between 25% and 50% of the volume below the element.

### **Solar plus wetback systems**

In some areas where a log burner or other low-cost fuel burner is used frequently it is possible to combine solar and wetback boosting as shown in Figure 99.

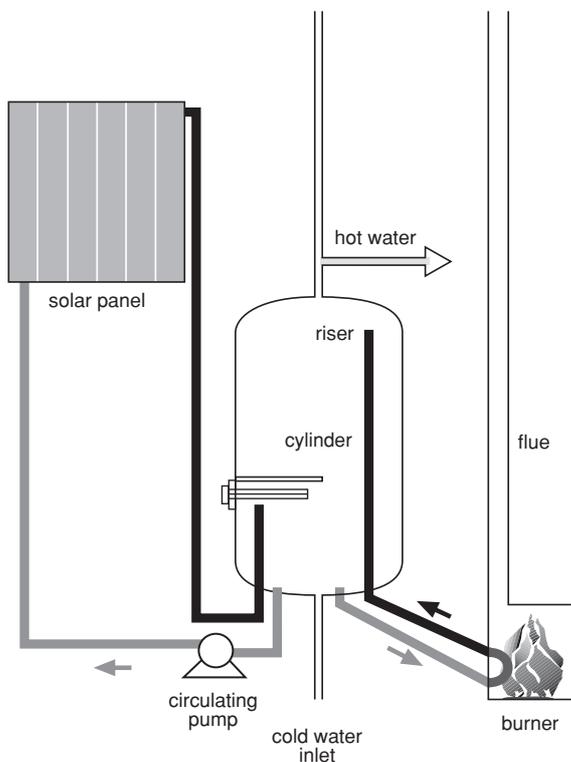
When this is done it is advantageous to set the solar panels at an angle which emphasises summer performance (flatter than the normal optimum).

This can be a very effective combination and there are some such combined systems which under normal operating conditions require no electrical boost at all.

It is advisable to keep the solar and wetback circuits completely separate. If this is not done, unusual and often deleterious interactions can occur between the two systems.

### **Other factors influencing the overall performance of solar assisted hot water systems**

Perhaps the most significant determinants of solar water heater savings, especially those with permanently connected electrical boosters, are the thermostat temperature and the pattern of use.



**Figure 99: Solar plus wetback**

If the thermostat temperature is set very high then the solar panel will, even in systems with two-stage cylinders, spend more time operating in conditions of lower efficiency (see HWB plot, Figure 94). Tests carried out by DSIR in 1979-1980 indicated that the overall annual savings of the “Colt” solar system (the best tested at that time) varied from 400 - 700 kWh per square meter of collector per year as the thermostat setting was changed from 70°C to 50°C.

However, it should be recalled that at present the building code requires hot water cylinders to be capable of being heated to 60°C.

In many systems the element can be turned off for long periods, and when water is used either early in the evening (when the water is at its hottest) and/or early in the morning so that the cylinder has cold water to present for solar heating, significant improvements in energy savings can be achieved.

In a new system it can be advantageous to specify a two element cylinder with one element set high in the cylinder as shown in Figure 58. This enables the user to effectively change the ratio of solar to electrical heating to suit the season and gives access to a fast recovery of a small amount of water if required.

Other installation factors which should be considered in the design of new systems include:

- minimising pipe runs both from collectors to cylinder and from cylinder to outlets;
- matching collector area to cylinder size and to expected use;
- providing flexibility and convenience of control; and
- avoiding shading of collectors by trees or architectural features.

### **Expected performance in NZ**

The primary indicator of performance in a solar system is the number of sunshine hours per year. This varies from about 1600 hours in Invercargill to about 2400 hours in Blenheim, with a national average about 2000 hour per year.

The energy falling on a horizontal surface ranges from about 6.5 kWh/m<sup>2</sup>/day in summer to about 1.4 kWh/m<sup>2</sup>/day in winter.

A figure frequently used for design purposes in New Zealand is a solar input of about 550 kWh/m<sup>2</sup>/yr with a thermostat setting of 60°C. This in turn leads to the oft-quoted figure of about 2200 kWh per year for a collector area of 4 m<sup>2</sup>. Expectations range from an

average of about 12 kWh/day in summer to about 2.5 kWh/day in winter. It should, however, be emphasised that these are averages and the day-to-day variation is large.

Because water is circulated through an exposed system there is a risk in some climates that the water can freeze in cold or frosty weather. Because water expands on freezing this can cause damage to the pipework or to the collector panel itself and special precautions must be taken in areas prone to freezing conditions to protect the equipment. These precautions are described in an earlier section of this Chapter.

## Heat pumps

A further alternative to direct electrical heating is the heat pump. Heat pumps have been used for many years in refrigeration and in space heating applications. Their use for water heating is comparatively recent.

A heat pump is essentially a refrigeration cycle working in reverse. Its basic mode of operation is illustrated in Figure 100.

A working fluid, usually a freon, is compressed and condensed to a liquid under pressure giving up its latent heat of vaporisation in a condenser. It is then expanded to a lower pressure whereupon some of the liquid evaporates and the liquid is cooled. Exposure of the evaporator to the atmosphere allows the fluid to draw in more heat until it is all vaporised. It is then recompressed and the cycle repeats. The net result is that energy is transferred from the colder region of the evaporator to the hotter region of the condenser. In a typical heat pumping cycle the amount of heat delivered at the condenser ranges from about 2 to about 5 times the amount of electrical energy which is used to drive the compressor. Some small amounts of additional power are often used to drive fans and/or pumps to circulate air and water. The ratio of heat produced to energy used to drive the heat pump is called the

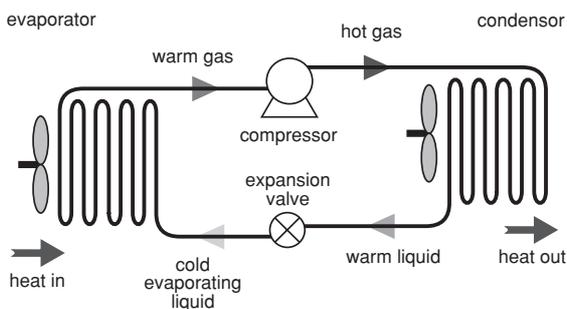


Figure 100: Basic heat pump

coefficient of performance (COP). In general, and depending on operating conditions, water heating heat pumps can have COPs ranging from about 1.5 to about 5. On average the heat pump will save 50% to 70% of the electricity that would be used in a normal electric hot water system.

There are two main water heating heat pumps available in New Zealand.

One (“Carrier Hot Shot”), is designed to extract water from the bottom of the cylinder heat it to 60°C and return it via a variable flow constant temperature valve to the top of the cylinder as shown in Figure 101.

When the stratification boundary reaches the thermostat in the cylinder the heat pump is turned off. The system is usually wired with a change-over switch as shown in Figure 102, which will allow the system to be operated on the heat pump or the element but not both. The Carrier unit has an electricity consumption of 850 Watts and produces 1900 Watts of heat to the water. Because the water is returned to the top of the cylinder the system has a quicker recovery characteristic than a normal electric element.

The Carrier heat pump and circulation system is packaged as a single unit which can be retrofitted to an existing hot water cylinder and requires no refrigeration expertise to instal.

The other heat pump system available in New Zealand, the “Quantum”, is available in two different configurations.

In both versions, the condenser is a coil wrapped round the hot water cylinder on top of which the compressor and associated components are mounted and the evapo-

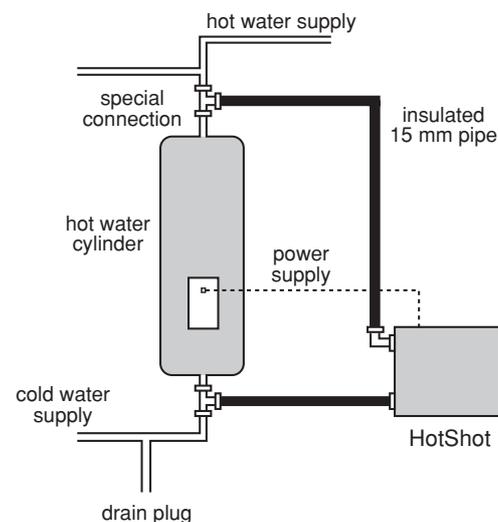


Figure 101 : Carrier “hot shot” system

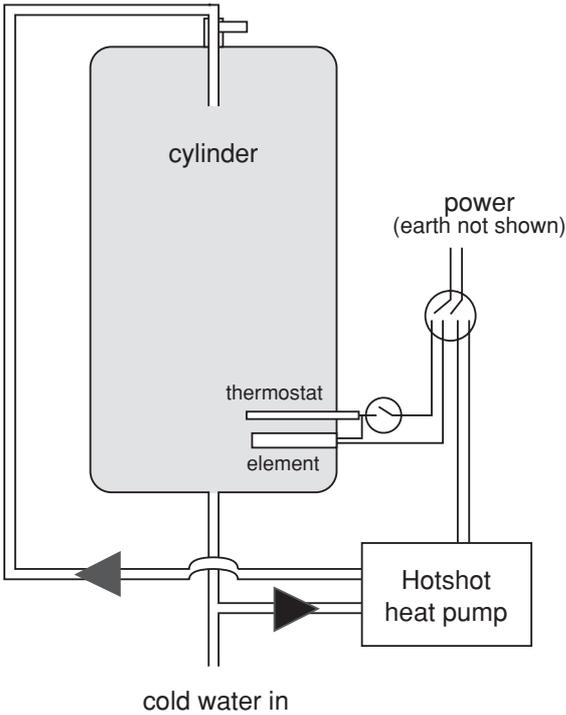


Figure 102: Change over switch

erator is exposed to the atmosphere, as shown in Figure 103.

The evaporator can be either a free standing unit or a set of flat plates attached to the roof of the dwelling within 6 m of the cylinder, as shown in Figure 104.

The roof-mounted system gains additional heat from the sun and is therefore said to be solar assisted. Because the two parts of the system have to be connected after installation this requires a refrigeration engineer as well as a plumber and electrician. The solar assisted version is said to have a coefficient of performance as high as 5 in sunny conditions. With compressor power of 650 watts the heat pump will deliver from 1000 to 3500 watts of heating to the hot water cylinder depending on the operating conditions (temperature of water ambient temperature and intensity of sunshine, etc.). The compact system which has the evaporator built separately round the cylinder requires no refrigeration expertise to install. Under favourable conditions the system can save up to 70% of the energy required for water heating.

Because of the way in which the heat is introduced to the cylinder in the Quantum system, the cylinder has a different recovery characteristic from both electrically heated and Carrier-type heat pump systems, with relatively little stratification and the whole cylinder rising gradually to the operating temperature.

Because of their relatively low power consumption, it is convenient to instal heat pumps on continuously

available (but still ripple controlled) power supplies, rather than night rate supply. This enhances the availability and enables the heat pump to provide a service that matches that of a conventional hot water system.

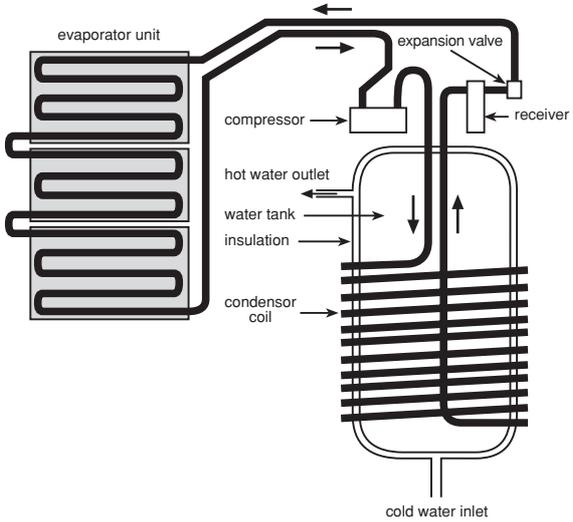


Figure 103: Quantum split system



Figure 104: Roof-mounted "Quantum" evaporator



# Chapter 9

## Distribution and Delivery

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To get the hot water from the storage cylinder to the actual use requires a piping system which itself can be the source of some of the problems encountered in domestic hot water systems. The commonest of these are:

- unacceptable waiting times for hot water to be delivered at the tap;
- unacceptable temperature at the tap;
- unacceptable flow at the tap (particularly in showers). This can be in the form of excessive or insufficient flow;
- fluctuation in temperature and /or flow. This again is particularly noticeable in showers and is more common in older and low pressure systems; and
- insufficient hot water.

All of these characteristics can be eliminated in new house designs if care is taken in the choice of cylinder size, element size, pipe layout, and selection of bathroom fixtures and other tapware. Some can be eliminated in existing systems by modifications of varying degrees of complexity.

### **Upgrading of existing hot water systems**

A high proportion of the deficiencies of hot water systems relate to showers.

### **Shower Flow**

A common defect in mains pressure systems is excessive flow in showers leading to excessive use of water. The two consequences of this are insufficient supply on the short-term basis and high water and energy use. It is estimated that there are about 100,000 showers in New Zealand with flows over 16 litres/minute. This is usually easily remedied by the installation of a lower flow shower head or a flow limiting device in the supply line to the shower.

The converse often applies to low pressure systems which constitute 78% of the domestic installations in

New Zealand. About 70% of systems have hot water pressures at the shower less than 2 m head. Many of these systems also have unequal pressure with low pressure to the hot water system and mains pressure to the cold water side and have ill-designed pipe layouts. This can lead to difficulty in controlling the water flows to a shower head and consequent difficulty in adjusting the shower temperature.

Flow variations caused by the use of other outlets in the house can further exacerbate this by causing sudden changes in the shower temperature which are uncomfortable and even dangerous. This is especially prevalent in systems in which the shower is fed by mixing hot water from two manually controlled taps rather than a mixer valve, but it can also occur in the latter systems. These effects can often be overcome by changing the pipe work so that the shower is supplied with hot and cold water at the same pressure and by ensuring that the shower lines are free from interference from other outlets.

An example of the appropriate changes is shown in Figure 105a and 105b.

The introduction of a tempering valve to a system with low pressure hot water supply sometimes results in a restriction of the hot water and an inadequate water flow at the shower head. There are now available mixer valves which are specially designed for unequal pressure and which use the high pressure cold flow to induce an improved flow of hot water (venturi mixers).

Another solution to the problem of low shower flows that is available to systems not connected to a wetback, is to convert the hot water supply from header tank or open vented, to valve-vented low pressure. Low pressure cylinders are designed for a working pressure up to 7.6 m and the installation of a valve kit to bring the system to this pressure can often result in a doubling or trebling of the pressure at the shower head from 2-3 m to 7.6 m. Conversion to a valve-vented low pressure system can also result in energy savings from the elimination of expansion losses and convection losses from header pipes and/or pre-cooling of the water in the header tank during cold weather (although this can be partly compensated by pre-heating in the header tank during hot weather).

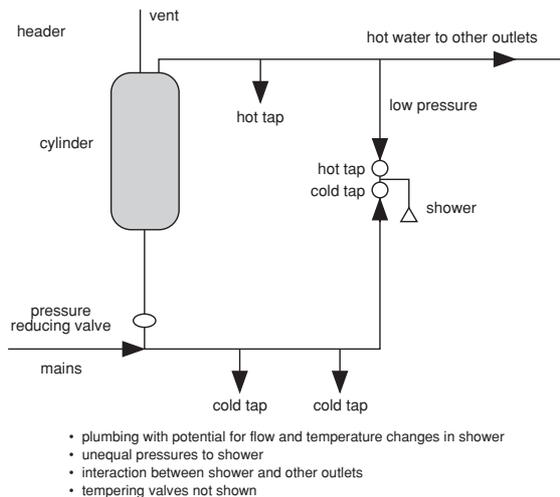


Figure 105(a): “Bad shower” plumbing

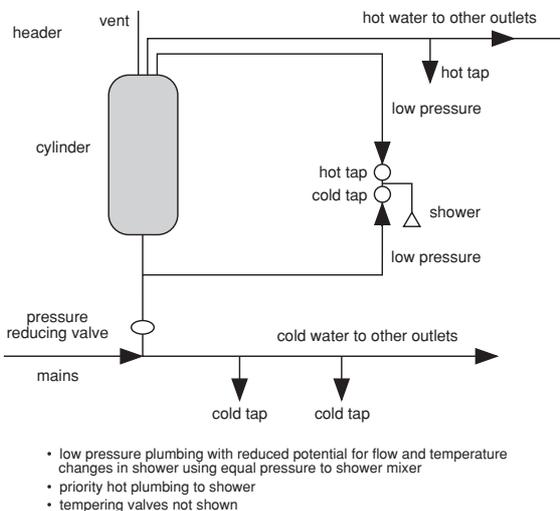


Figure 105(b): “Good shower” plumbing

## Excessive delivery temperature

Old-style rod-type thermostats are notoriously inaccurate and often develop a large dead band, resulting in high temperatures and large temperature variations (between element on and element off) in the storage cylinder.

Many systems have storage cylinders that are too small for their current service and this is often compensated for by running the cylinder at an increased temperature. In some cases, poor hot water flow has been partly compensated by increasing the storage temperature. These conditions are both energy wasteful and unsafe.

The safety issue can be addressed by the installation of a tempering valve and the energy wastage by the introduction of an expansion type (user adjustable) thermostat and, where the cylinder size is adequate, by reducing the storage temperature.

## Inadequate quantities of hot water

This condition is often the result of increasing use of hot water in households with small (135 and 180 litre) cylinders fitted with low wattage (1500 W) elements. When the daily water use pattern is appropriate and the system is not “night rate” controlled, a partial cure can sometimes be effected with a larger element. Replacing a 1500 watt element with a 3 kW one in a 135 litre cylinder will reduce the recovery time for a full cylinder from 6 hours to 3 hours. Raising the operating temperature (provided that a tempering valve is fitted) from 60°C to 70°C will provide about an extra 20 litres of effective capacity at a tap temperature of 45°C. A user adjustable thermostat will allow adjustment of the storage temperature from time to time to allow for changes in water need thus minimising the energy wastage associated with high storage temperatures.

The ultimate solution to shortage of hot water is of course the installation of a larger cylinder and this should always be considered when a cylinder is due for replacement. Indeed this is the time to consider a general upgrade of the whole hot water system.

Older systems (pre-1988) will almost certainly have cylinders with poorer insulation and consequent higher heat losses. This can be of particular concern in systems with smaller cylinders on night rate tariff where the temperature is not maintained by energy input during the day. In a 135 litre cylinder each kWh of energy loss corresponds to a temperature drop of almost 6.5°C. If the heat loss is 3 kWh/day, as it could be in an older cylinder, this will correspond to a temperature drop of about 10°C between 7 am, when the power supply ceases, and 7 pm.

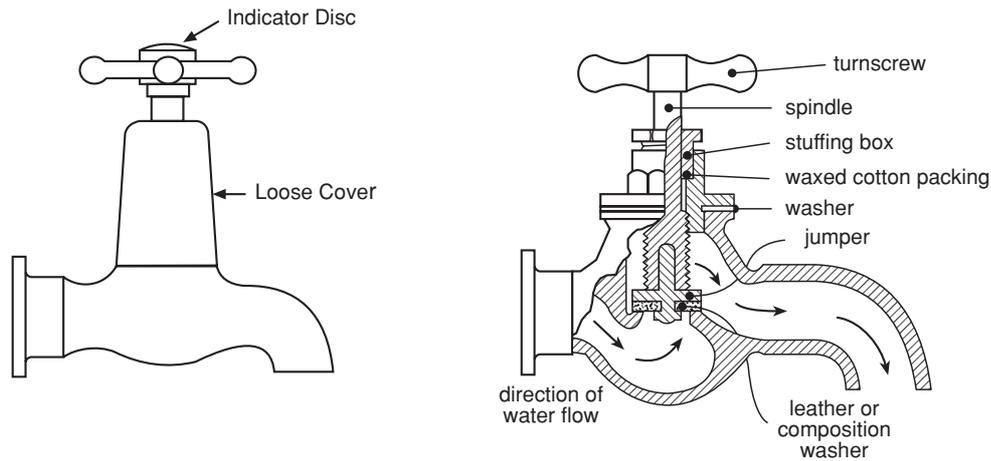
The use of an insulating blanket will reduce the energy loss thus saving power and will reduce the temperature drop, thus ensuring a better hot water supply.

## Delivery

### Taps

The number and variety of final delivery devices, taps, mixers and shower heads, is too numerous and the styles vary too frequently to be dealt with in detail in this book. However, this section provides a brief outline of the various generic types of delivery devices.

The simplest delivery device is the tap. Older style taps used a compression (washer) type valve, as shown in Figure 106. These have several turns of the handle between off and fully on and therefore provide a good



**Figure 106: Compression-type tap valve**

range of flow control. Simple taps of this kind are applicable to all supply pressures and provide reasonable flow even at low supply pressures. They are simple in construction and relatively easy to service, requiring only replacement of the washer and (very infrequently) recutting of the seat, both of which tasks can be performed *in situ*. The simplest sink and basin plumbing arrangement has separate taps for hot and cold water and mixing takes place in the sink, basin or bath. Such systems avoid problems that might arise from unequal hot and cold water pressures. They do, however, have the potential for providing dangerously hot water at the tap outlet, particularly in the absence of a tempering valve on the cylinder outlet.

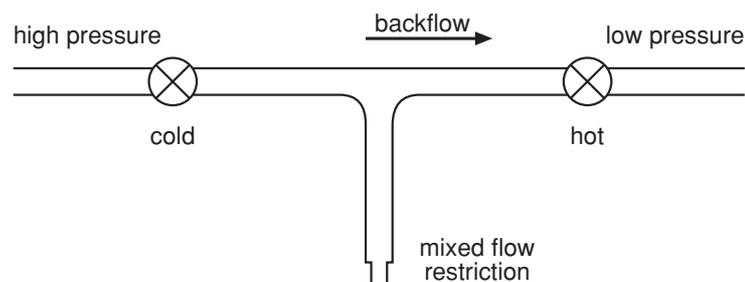
Simple taps come in a wide range of configurations for direct bench or basin mounting and for remote mounting at a short distance from the actual outlet as on washing machine connections.

In some cases, a hot and a cold tap are connected to a single outlet on a hand basin or kitchen sink (as shown in Figure 107), so that mixing takes place before the water stream enters the sink or basin. This is a slightly safer arrangement than individual outlets, although it is

still possible to get maximum temperature water by turning on the hot tap only. This type of arrangement generally works well, although in systems where the cold water pressure is much higher than the hot water pressure, it is possible to restrict the outlet and cause cold water to flow “backwards” up the hot water line. Some outlets have gauze aerator devices that present quite a high flow resistance at the outlet and these are particularly susceptible to reverse flow in unequal pressure supplies.

The problem can also arise in systems fitted with flow restrictors where there is unequal pressure for hot and cold supply. It has been alleged it can happen even in higher but unequal pressure systems. For this reason, some installers recommend that pressure control (pressure reducing and pressure limiting) devices be installed at the inlet to the household supply, rather than on the hot water supply only, to ensure equal pressure supply to all outlets.

Many modern tap designs use ceramic inserts in place of the simple washer. These valves operate from closed to fully open over a quarter of a turn of the control lever. In many ceramic disc taps, the aperture through which



**Figure 107 : Separately controlled mixing tap**



**Figure 108: Single lever mixer**

the water flows is small and therefore in order to achieve a reasonable flow it is necessary to have a high pressure drop over the valve.

The next level of complexity is the single lever mixing valve in which the total flow and the ratio of hot to cold are controlled by a single lever whose rotational position sets the ratio and the lift sets the flow. In these taps the temperature of the delivered water is dependent on the ratio and is not thermostatically controlled. Most single lever taps use ceramic cartridges, and many require a reasonably high pressure to provide an adequate flow. There are, however, single-lever taps now available that work well down to very low pressures.

Various models of single lever tap have different characteristics and it is necessary to choose a tap that will operate satisfactorily at the pressure chosen for the house. Good quality taps are sold with information on the pressure range that the tap is suitable for.

A particular design of single lever mixing valve is made specially for unequal pressure supply. This has an internal venturi in which the cold (high pressure) flow generates a low pressure region into which hot water is drawn. The lowered pressure in the venturi creates a greater pressure drop in the hot water line and increases the hot water flow thus countering the lower flow that would otherwise persist.

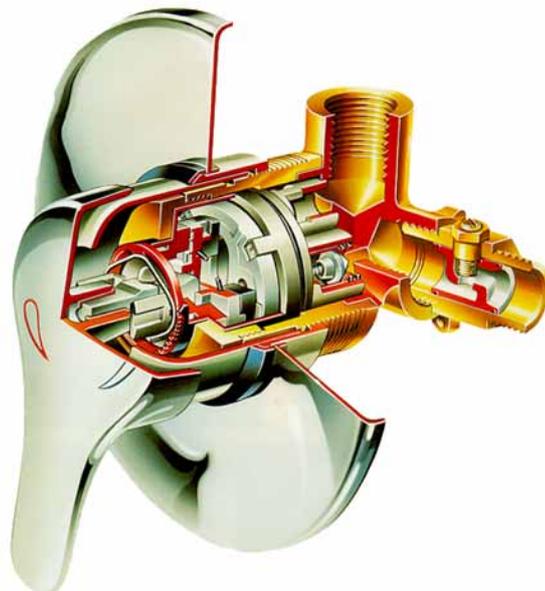
Another range of mixer valves, used mostly on showers, has a thermostatic control of the temperature. These usually have separate controls for temperature and flow. A fully thermostatic shower valve is shown in Figure 111.



**Figure 109a: Shower mixer tap - external**



**Figure 109b: Shower mixer tap - internal**



**Figure 110: Single lever shower mixer controlling both flow and hot/cold ratio**

### Shower heads

The shower head itself can be a major restriction in the flow and some shower heads are unsuitable for low pressure operation. Others offer very little flow resistance and when used on a high pressure system will lead to excessive flow. Such flows can be remedied by the use of flow restrictors on the shower head or on the feed

lines to the shower, or by changing the shower head itself.

For those concerned about energy and/or water conservation, it pays to measure flow in showers. In general, although dependent on the shower head, a good shower can be achieved at between 6 and 8 litres per minute flow.

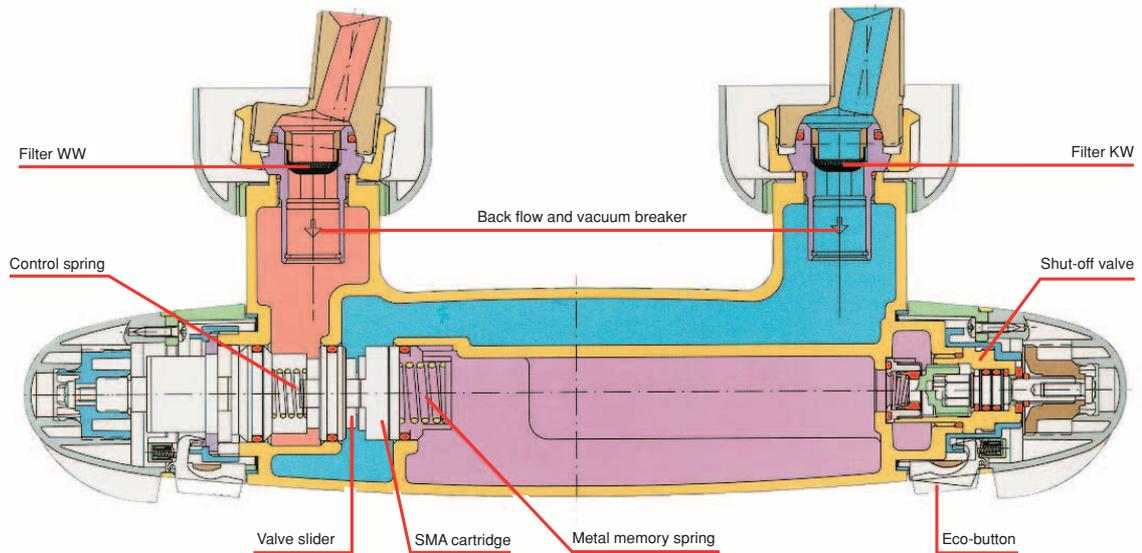


Figure 111: Thermostatic shower mixer



# Appendix 1: Useful Water Temperatures

0°C	Freezing point of water at sea-level
4°C	Temperature of water's maximum density
4°C	Typical average minimum water temperature supply, South Island and North Island Central Plateau
8°C	Approximate minimum ambient water temperature, North Island excluding Central Plateau
12°C	Approximate average water temperature in North Island excluding Central Plateau
20°C	Approximate maximum cold water supply temperature in New Zealand
20°C - 45°C	Temperature range in which <i>Legionella</i> bacteria flourish
38°C - 40.5°C	Bathing temperature for children and infants
40°C - 43°C	Bathing temperature for adults
45°C	Maximum delivery temperature to personal hygiene outlets for early childhood centres, schools and old people's homes. NZBC G12 (1994 revision)
50°C	Maximum delivery temperature to all personal hygiene outlets (proposed NZBC G12 ASI(1997 revision))
50°C	Child's skin is burnt in 40 seconds
55°C	Child's skin is burnt in 10 seconds
55°C & above	Temperature range in which Legionella bacteria cannot survive (NZBC)
55°C	Maximum delivery temperature to personal hygiene outlets (other than 45°C requirements) NZBC G12 ASI (1992)
55°C - 60°C	Dishwashing temperature
60°C	Child's skin is burnt in 1 second
60°C	Minimum temperature for storage water heaters to prevent the growth of Legionella bacteria NZBC G12 ASI (1992)
60°C	Normal setting for domestic gas water heaters (where not user adjustable)
60°C - 65°C	Maximum temperature for many makes of domestic appliances using hot water
65°C - 70°C	Traditional setting for domestic electric thermostats (carries a significant scalding risk)
68°C - 70°C	Maximum setting for domestic gas thermostats
70°C	Child's skin is instantly burnt
70°C	Maximum setting for typical domestic mains pressure electric thermostats
75°C - 85°C	Common temperature with a wetback. Possible summer time solar water temperature
77°C	Temperature required for sanitising purposes (not normal dishwashing)
80°C	Maximum recommended temperature for high pressure cylinder
82°C	Maximum thermostat setting for thermostats in special heavy-duty water heaters
82°C - 92°C	Temperature at which the energy cut-out device will operate on fixed setting thermostats
90°C	Maximum recommended temperature for polybutylene pipes
87°C - 95°C	Temperature at which the energy cut-off device will operate on adjustable thermostats
93°C - 95°C	Temperature at which a T & PR valve subjected to normal working pressure will start to dribble
97°C	Nominal thermostat setting for boiling water units
100°C	Boiling point of water at sea-level
121°C	Boiling point at 100 kPa (low/medium cylinder pressure)
200°C	Boiling point at 1400 kPa (highest pressure cylinder)

