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HOT WATER OVER TIME– THE NEW ZEALAND EXPERIENCE

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ABSTRACT

People today expect a ready supply of hot water. Just over 60 years ago, the 1945 Census reported 27% of households lacked hot water service. The paper reviews the provision of domestic hot water from the 1800s through to today. Coal and wood fires, solid-fuel ranges, coal gas, solid-fuel burners, electricity and natural gas have all played a role.

The paper reviews house planning guidance and Censuses, linking historic data to the results of the Household Energy End-Use Project (HEEP) which has collected energy, temperature and water use data from a nation-wide random sample of 400 houses.

Today 88% of hot water systems are electric (mostly low pressure) and 81% of these deliver water over a safe 55°C, in some cases due to the inaccuracy of rod (bi-metallic) thermostats. New cylinders are likely to be mains pressure, which will, in the absence of low-flow showerheads, increase water and energy use.

Keywords
Domestic hot water, electricity, gas, wood, shower, bath

HOT WATER OVER TIME– THE NEW ZEALAND EXPERIENCE

"Men have gone to the moon and marvelled, but no greater event occurred on this earth than the abundance of soap and the unheralded arrival of hot and cold water by the turning of a tap. It is a gift of my lifetime, as is the leisure to use it. A rocket to the moon put millions of miles on to exploration potential; but hygiene – made possible by instant hot and cold water – probably doubled our life span." (Lee 1977)

Today the provision of hot running water is considered a fundamental household requirement, yet only it is only since the 1960s that the large majority of New Zealand houses have had an on-demand hot water supply.

HOT WATER SERVICE

The provision of domestic hot water divides neatly into two methods:

- batch production, often based around carrying cold water to a pan or other holder above a fire; and
- continuous production, with piped water flowing into a device heated by electricity, gas or solid fuel.

Figure illustrates the different types of hot water cylinders found in the Household Energy End-use Project (HEEP) sample. Cylinder 'grade' refers to insulation levels.

Electric D-grade	Electric B-grade	Electric A-grade	Gas Instant	Gas Storage

Figure1: Examples of hot water cylinders

Prior to the 1945 Census there is no statistical data on the availability of hot water in New Zealand homes. In that Census, for the first time a question was asked about the availability of hot water supply. Although the question has changed over time, a general comparison can be made (see Isaacs et al. 2005 for detailed analysis).

In 1945, 27% of households lacked a hot water service, but over the next decade this proportion more than halved so that by 1956 only 11.6% of household lacked a hot water service. The proportion fell to 5.9% by 1961 and 1.1% by 1966. By 1996 – the last Census in which a question on hot water service was asked – there were only 4,917 dwellings (out of the then total of 1,276,332 'Private Occupied Dwellings') which lacked a hot water supply (see Isaacs et al. 2005 for detailed analysis).

Even in 1945 88% of households had either a bath or shower – suggesting the presence in some of the 15% of households that lacked a permanent hot water service. In those houses the hot water would have been 'batch brewed', just as would have been the case 50 years earlier. The number of homes with a bath or shower grew rapidly, and by 1966 one or the other was found in 97.7% of households.

As from 1966 most houses had a hot water service, the Census could then ask about the fuels used. It was mainly electricity at 84% in 1966, 92.6% in 1986 and 88.1% in 1996. In the 1996 Census at total of 1,046,886 households (82% of all households) reported only one fuel used for hot water provision – 951,759 (75% of all households) reported only electric water heating, 83,646 (7%) only gas water heating, 10,821 (0.8%) only solid fuel water heating and 660 (0.05%) only solar water heating. Only 4,917 houses reported 'no hot water service'.

SOLID FUEL

A container of water collected from the roof, nearby stream, river, lake or well and heated over an outside open fire has been used since time immemorial. Early European settlers shifted from an outdoor fire to a chimney with an indoor opening, but it was not until the 1860s (a mere twenty years after New Zealand had become a colony of Great Britain) that piped water was available in the main cities.

By the mid-1860s piped water was laid to at least the central city areas in Dunedin, Wellington and Auckland, but it took another twenty years before piped water was available in wealthy homes. It was not until the early 1900s that centrally-provided and treated piped water started to become common place. The provision of hot water continued to be a batch process, whether based around a kerosene tin on the (coal or wood) stove or hung from a hook over an outside open fire (Lee 1977).

The 'copper' – once found in every home laundry or 'wash-house' – was a larger, more permanent version. The large copper container held about 14 gallons (60 litres) of water and was permanently mounted in a concrete or brick stand. A fire was lit underneath, and after some hours of firstly filling the copper and then heating the water, clothes were 'boiled' using home-made, and in later years store-brought, soap. Agitation was by a broom handle or some other suitable piece of wood.

A water tank could be added to the kitchen range. It could be filled by hand or connected to the household water so that as hot water was drawn off it was replaced. This 'push-through' system was controlled by the cold tap feeding water in, meaning the hot water outlet acted as a safety vent, dribbling scalding hot water or even steam into the sink as the cold water expanded with heat (NZTCI 1964).

Chip heaters were a further development – a solid fuel burner with no oven or hotplate. A water jacket around the fire took heat from the hot gases, which then disappeared up the flue (NZTCI 1964).

A further step was the fitting of a coil in the back of the fire, feeding hot water into a near by cylinder by thermosyphon. The term 'wet-back' is uniquely used in New Zealand to describe *a heat exchanger fitted at the rear of an open fire or stove for providing hot water* (Milton 1994).

All these systems had a major failing. Close contact between the flame and the cold surface containing the water resulted in poor combustion and hence air pollution.

Unburnt soot quickly clogged the chimney, so a chimney slot was desirable and the regular cleaning an unpleasant chore.

Even today, solid fuel provides hot water in many homes. In modern 'wetbacks' the water heating coil is placed well away from the burning wood, extracting heat from the flue gases rather than the flame. Wetbacks are found in about 15% of New Zealand homes and supply about 5% of the national hot water energy demand (Isaacs et al. 2006).

GAS

Town (or 'coal' or 'manufactured') gas – produced by the destructive distillation of coal – was available first in Auckland in 1862 but by the 1870s there were gasworks in Wellington, Christchurch and Dunedin. By the end of World War II there were 46 gasworks with a total of 200,000 consumers. The 1959 discovery of natural gas at Kapuni reversed the decline in gas use when it became available in the North Island from 1971. Town gas water heaters were replaced with natural gas systems or by cheap electricity systems in regions not serviced by reticulated natural gas.

There are a number of ways to use gas to make hot water, as well as using a tank based on the stove.

The town gas 'geyser' or 'califont' followed the approach of the solid fuel chip-heater, with the gas burning inside a water jacket. The geyser could fume away above the bath or sink, where apart from the noxious smell of burnt gas there was always the possible excitement of an explosion if the gas initially failed to light (Wright 1960).

Gas storage water heaters followed. By the 1930s, home cook books carried large advertisements showing an insulated tank capable of supplying "*hot water in abundance any hour day or night for every purpose"* (Connor 1930).

With increasing distribution of cheap hydro-electricity and the associated decline of the coal gas industry in the 1950s, electricity rapidly became the dominant fuel. It was not until natural gas became available in the 1970s that gas started to make a comeback for water and space heating (Williamson & Clark 2001). Even in 2004, only 14% of New Zealand homes had a mains gas connection (Statistics NZ 2004h) although large bottle (45 kg) LPG is used in non-reticulated areas for hot water.

A range of gas storage and continuous flow hot water heaters are now available. Domestic gas storage water heaters range in volume from 135 litres to 360 litres consuming gas at rates from 35 MJ/hr (10 kW) to 200 MJ/hr (56 kW), while providing hot water flows from 3 to 13 l.min-1 (averaged over an hour). Gas continuous water heaters consume 80 MJ/hr (22 kW) to 250 MJ/hr (70 kW) while providing a hot water flow from 10 to 32 $l.min^{-1}$ (data from www.gas.co.nz, accessed 10 June 05).

ELECTRICITY

In 1886 Reefton had the first public supply of electricity in the Southern Hemisphere, but electricity was not widely available throughout New Zealand until the first decade of the 20th century.

New Zealand household electric hot water heating dates back to 1915, when Lloyd Mandeno (then the Tauranga Borough engineer, but later a major force in New Zealand electricity development) developed one of the world's first electric storage hot water heaters for use in New Zealand's first all-electric house. Built by Tauranga resident R.S. Ready, it featured electric cooking, house heating, ironing, lighting and of course water heating (Mandeno 1974).

Mandeno built the hot water container of heavy gauge corrugated galvanised iron and fitted two elements, one 350 W and one 500 W. For comparison a modern cylinder would typically have one 2 or 3 kW element, with larger elements for larger cylinders. This first tank sat in a larger container, around which he packed a 6-inch-thick (15 cm) layer of screened pumice for insulation. The whole package was placed under the roof above the ceiling, with short drops of concealed pipe leading to the kitchen sink and the bathroom below.

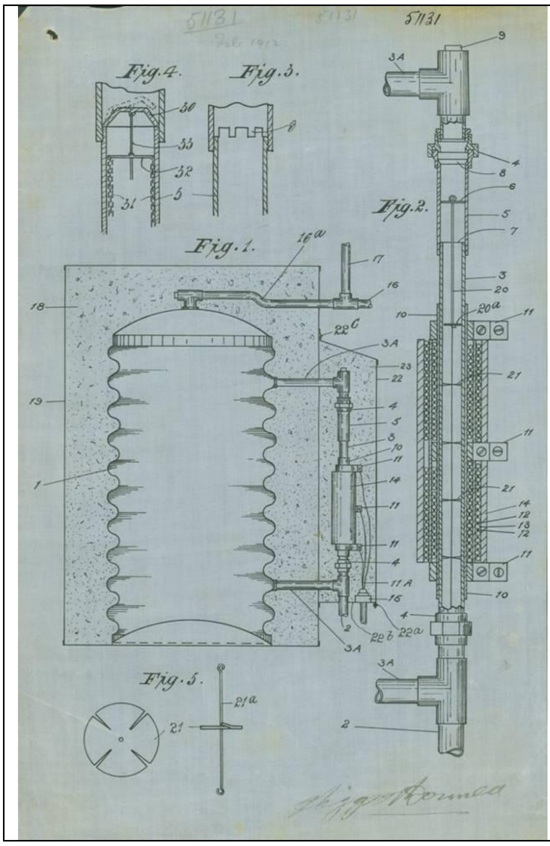

Figure 2: "An Improved Electrical Water Heater" (1923) NZ Patent 51131

The fatal flaw in the cylinder design did not become obvious for a couple of years, when the galvanised iron corroded through (Mandeno 1974). The solution – containing the water in a copper cylinder – remained the basis for the low-pressure electric hot water cylinder still in use today (Rennie 1989).

On 25 October 1923, Mandeno patented the first New Zealand electric hot water cylinder (Mandeno 1923). This was not the world's first electric water heater– the US Patent & Trademark Office records storage type electric water heaters with continuous flow (as opposed to batch heaters) dating from at least 1909 (e.g. US Patent 938,237 26 October 1909) – but it was an important step .

Some points of interest in Figure 2:

- **no separate thermostat** – the heated water lifted a small disk inside pipe (5), permitting the convection of heated water into the storage tank and its replacement by cold water from lower in the tank
- **external element inside case** (14) allowed the pipe to be automatically descaled by the movement of a chain or disk attached to the heated water release disk, and presumably replacement without disconnecting the cylinder. Asbestos and mica were used for insulation.
- use of **tank insulation** (18) – the tank was insulated with pumice or other appropriate material.
- **corrugated tank and bottom dome** (1) – provided more strength than flat material. Hot water system patents earlier than 1910 show neither tank insulation nor tank corrugations.

The domestic price of electricity halved between 1923 and 1935, which coupled with the lack of coal gas 'smell' and a more modern image rapidly increased market penetration. Electric load management could be achieved by a consumer operated switch – permitting the choice of either hot water or the cooking range, but not both at the same time (Rennie 1989).

By the late-1940s, the modern home cook book provided detailed electrical guidance for the householder with little knowledge of electricity:

> *The size of heater required is dependent on two factors:—*
>
> *1. Quantity of hot water required.*
>
> *2. Time in which heating must be accomplished.*
>
> *Water heating during off-peak load hours is generally procurable at cheap rates. Hours of use are usually from 10 p.m. to 7 a.m. All day water-heating service is also generally procurable at reasonable rates. For night heating the size of electric element required is approximately 1 kW per 20 gallons storage capacity. For 24 hours service this may be halved, i.e. 500 watts, or 600 watts will be found to be ample. Recently there has been considerable development in storage cylinders of the quick recovery* (Whitcombe & Tombs, 1948).

A 40 gallon (180 litres) cylinder with only a 1.2 kW heater can take up to 8 hours to provide a full tank at 60°C. No problem if the main hot water loads were large and intermittent – washing dishes, washing clothes or a bath for the household – but this was not the sole issue of concern.

New Zealand was in an unusual situation – electricity generation was peak power constrained but as the majority of generation was from hydro stations, only in times of water shortage was there an energy problem. Originally electricity for water heating was sold on a fixed annual charge, irrespective of consumption, but severe power restrictions resulted in changes. Metering was made compulsory along with the fitting of thermostats (Speer 1962).

The impact of the electric hot water cylinder on the electricity system was huge. A mere 34 years after the first one, 32% of the nation's total electric use was going into domestic hot water (NZSI 1949).

Slowly the dedicated electric hot water system took over from the kitchen range or chip heater as the way to make hot water. The local electric power boards, wanting to ensure its customers had adequate hot water without unreasonable demands on their grid then started to control the times of cylinder operation, its size and element.

Time clock controls were first installed on storage hot water cylinders in the 1920s, and were followed by 'pilot wire' controls (a separate signal wire being installed in each house) in the 1930s. The 'ripple control' system (a signal at a special frequency is feed through the power lines and detected by a tuned relay in the house) was first introduced in 1949 by the Waitemata Electric Power Board, and then quickly spread throughout the country (Rennie 1989).

Although small cylinder volumes and heating elements may have been satisfactory for one bath a day, they fail to meet the needs of modern households. One of the major reasons has been the shift from baths to showers – in 1971/2 showers were solely, or mainly, used in 41% of households (NZ Department of Statistics, 1973a) but today it is over 94% (Isaacs et al. 2006) – placing very different demands on the hot water system.

Still Mandeno's legacy remains – the 1996 Census reported 88% of New Zealand homes have at least one electric hot water cylinder (Statistics NZ 1998). Nowadays residential hot water uses 31% of household electricity and 8% of all electricity (Isaacs et al. 2006).

HOT WATER TODAY

FUELS

Table 1 compares domestic hot water fuels for USA, England, Australia and Canada – as a house may have more than one fuel, columns do not necessarily add to 100%. New Zealand stands out as having the highest (88%) proportion of electric hot water systems while England has the highest proportion of natural gas (76%) fuelled systems. Australia and Canada have similar proportions of electric systems (51%), but differ in the greater penetration of natural gas in Canada. The 'Other' fuels in Australia include solar water heating, bottle LPG and solid fuel systems.

DHW fuel	USA (EIA 2004)	England (ODPM 2003)	Australia (ABS 2005)	NZ (Census 1996)	Canada (NRC 2005)
Electric	38%	12%	51%	88%	51%
Natural gas	54%	76%	36%	8%	44%
Fuel oil	4%				4%
LPG	3%		3%		
Other (inc Don't Know, Solid)	1%	12%	12%	19%	0%

Table 1: DHW fuels – international comparison

An examination of countries for which regional data is available, suggests a link between the use of hydro-electricity and the proportion of houses served by electricity hot water systems. For example, a state-by-state examination of Australia reveals that Tasmania (90%) has the highest proportion of electric systems, followed by Queensland (68%) and New South Wales (64%) (ABS 2005). Ninety percent of Tasmanian electricity is generated from hydro sources (Hydro Tasmania 2005)

WATER PRESSURE

The 'traditional' New Zealand electric hot water system is 'low pressure', based around a header tank feeding an open vented cylinder (under 3.7 m head). The trend has been to 'medium pressure' using a pressure reducing valve (generally 7.6 m head), and more recently to 'mains pressure' hot water systems.

79% of electric storage systems are low pressure, but only 32% of natural gas systems. As low pressure electric hot water cylinders fail, it appears they are being replaced by mains pressure systems. This has two implications for householders:

1. copper low pressure cylinders have a longer life than glass-lined steel.
2. low pressure systems have lower shower flow rates

The consequences of the shorter cylinder life are in the future, but the higher shower flow rates will have an immediate impact in higher water and energy costs.

Table 2Table provides an analysis of the warm water flow rates for the about 450 showers for which pressure information was available from HEEP, divided into the star rating bands used for the WaterMark Certification Scheme (WMCS) (SAI Global 2006).

Some showers delivered water at under 5 $l.min^{-1}$, which without a special head would give unacceptable shower quality. A separate category has been used for under 5 $l.min^{-1}$, and thus the three-star category includes water flows from 5 to 9 $l.min^{-1}$

Description	WMCS	Mains	Low	TOTAL
Very low flow (< 5 $l.min^{-1}$)	< 5 $l.min^{-1}$	8%	29%	23%
Low flow (5 - 9 $l.min^{-1}$)	*** or better	20%	52%	44%
High flow (9 + $l.min^{-1}$)	** or worse	72%	19%	33%

Table 2: Shower warm flow rates by WMCS rating

Table 2 shows that although about one half (52%) of the low pressure showers deliver warm water at three stars or better, this is the case for only one fifth (20%) of the mains pressure systems. Overall, more than two thirds (67%) of New Zealand showers are already at three stars or better – but this is driven by the high proportion of low pressure systems and will change as high pressure systems are installed.

WATER TEMPERATURE

New Zealand Building Code, Clause G12 :Water Supplies effectively requires the use of a tempering valve to permit storage to be above 60°C and delivery to be below 55°C in new buildings and installations (DBH 2007). Table 3 summarises the water temperature for HEEP electric storage cylinders at the nearest tap and the cylinder thermostat setting. Tap temperature measurements were made on all systems, but thermostats on gas systems very seldom have a temperature scale. 83% of the electric water heaters had rod-type, bimetallic thermostats while the remaining 17% had a user adjustable capillary thermostat. Rod-type thermostats are not noted for their accuracy (e.g. Williamson & Clark 2001), and this was found in the field.

Table 3 shows that 81% of the electric hot water cylinders delivered water at temperatures over 55°C (i.e. unacceptably hot). 59% of all other fuel types (gas, solid fuel) delivered water at over 55°C

	Cylinder Thermostat		
Tap Temp	Under 60°C	Over 60°C	TOTAL
Under 55°C	14%	6%	19%
Over 55°C	40%	40%	81%
TOTAL	54%	46%	100%

Table 3: Count of thermostat setting vs. tap hot water temperature

Only in 9% of cases was the tap temperature within ±1°C of the thermostat temperature. In 36% of the cases the temperature was within ±5°C but in 66% it was within ±10°C. A linear regression found a reasonable relationship (r^2 = 34%) centred around 61°C, but there is a wide spread of temperature differences. The distribution of the temperature differences between the delivered water temperature and the thermostat setting is close to a normal distribution (skewness = 0.17), and with a sample standard deviation of 11.2°C.

New Zealand completed conversion from British units (Fahrenheit °F) to the SI (metric) system (Celsius °C) in 1976 (McLauchlan, 1989). A reasonable assumption is that if a thermostat is marked in Fahrenheit it was made prior to 1976. When the thermostats are separated into temperature markings, a linear model found different intercepts: 64°C (r^2 = 44%) for those marked in °F and 61°C (r^2 = 32%) marked in °C. A t-test suggests these are two different distributions (t=4.33, p-value 0). This would suggest that older rod type thermostats deliver hotter water than the newer versions.

It is unfortunate that these results show that thermostat inaccuracy results in the delivery of over-hot, often dangerously hot water. Of particular concern are the three electric storage cylinders (0.7% of the sample) that delivered water over 90°C (usually a failed thermostat) and the additional 15 that delivered water between 80°C and 90°C (3.5%). All but one of these 18 cylinders lacked a tempering valve. This would suggest that the use of tempering valves reduces the chance of very hot water being delivered to the tap, and hence reduce the possibility of hot water burns.

DISCUSSION

Our expectations for the supply of hot water have changed greatly in the past century. No longer is batch produced hot water acceptable as households expect to have continuous production with adequate supplies to meet every need. A shift from baths to showers has been supported by this shift in hot water production.

Interestingly, apart from the ‘copper’ and stove based hot water systems, all the methods once used to provide household hot water are still found and used in New Zealand houses today. Town gas has been replaced by natural gas, small electric storage tanks and elements have been replaced by larger systems, solid fuel systems have been redesigned, but they continue to be used.

As a consequence of the long life of hot water systems, and the difficulty and expense of changing, hot water energy use reflects the historical market developments – notably in the high proportion of electric storage systems – at 88% this would appear to be the highest in the world.

The shift from low pressure hot water systems to higher pressure systems with their higher flow rates will have significant implication for future water and electricity demands. In particular low pressure systems are already largely low flow, but higher pressure systems will require low flow shower heads to maintain the low water use.

Unacceptably high temperature hot water is found in too many New Zealand households – in electric storage cylinders the lack of control relates to the use of rod-type thermostats. Of particular concern are the 4% of electric storage hot water cylinders that are delivering water at dangerously hot temperatures of over 80°C.

With both water and energy becoming more expensive an ongoing evolution of domestic hot water systems is essential for the future. The use of heat pumps and solar holds promise for electric hot water systems, while gas water heating technology has seen the condensing boiler, which although well used in Europe have only recently been introduced into New Zealand. There seems to have been little development of solid fuel water heating systems, but these could provide real benefits by maximising household flexibility and minimising investment in central electricity generation. Currently, the regulations governing hot water systems are under review, and include measures to minimise the CO_2 emissions for hot water, which would require a shift away from electric resistance hot water systems.

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