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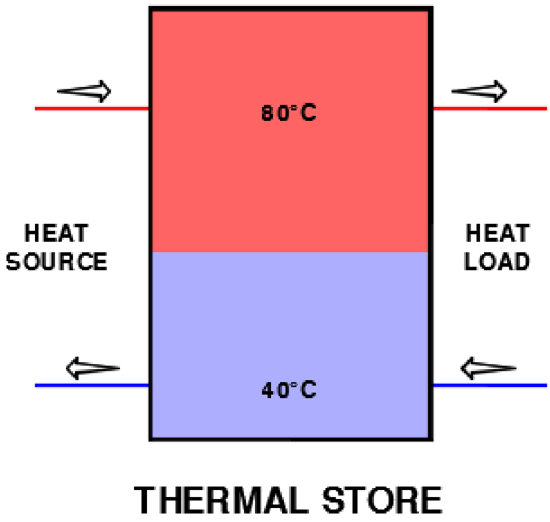
Thermal Storage Vessel Sizing

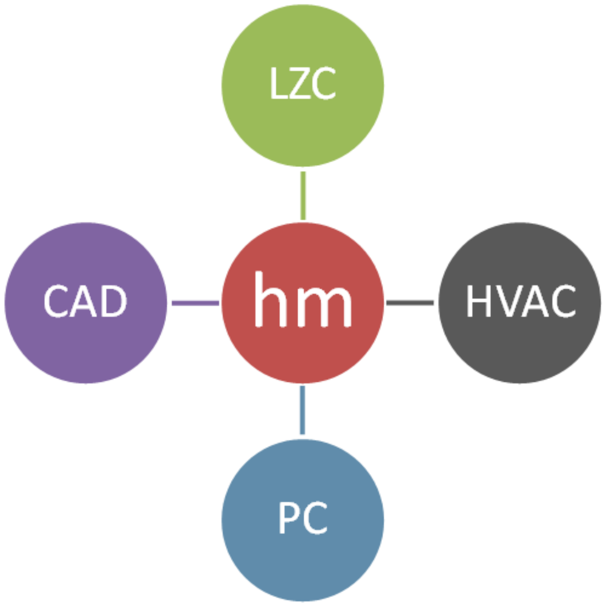


Summary

This article provides information on sizing a thermal storage vessel. A buffer vessel or thermal store, captures heat to provide a buffer between load variations and improves thermal efficiency.

Tags: homemicro.co.uk; buffer vessel; thermal store; biomass boiler; ASHP; GSHP; Sizing a buffer vessel; accumulator tank; heating vessel

The web article relating to this subject can be found here:
http://www.homemicro.co.uk/lzc_vessel.html



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INTRODUCTION

This guide provides information on the sizing of thermal storage vessels. The terms accumulator, buffer vessel, thermal store, tank and cylinder are often used interchangeably (see Definitions), including in this guide. Essentially the advice in this guide is on buffer vessels and thermal stores used to maximise thermal efficiency and provide plant protection.

A buffer vessel is a vessel that holds water, increasing the overall volume content of the heating distribution system. The additional water volume absorbs heat (thermal storage) produced by the heating appliance in low load conditions, which the building or system does not yet require principally to prevent plant short cycling. The vessels also provide hydraulic separation between primary and secondary circuits. Buffer vessels are also used with chilled water systems for the same reasons.

This guide outlines factors that affect the selection and sizing of buffer vessels for a variety of different heat sources to include heat pumps, biomass boilers and combined heat and power plant.

MANUFACTURERS ADVICE

Consulting equipment manufacturers for best advice is strongly recommended. Manufacturers' advice will be invaluable to ensure the most appropriate type of vessel and control regime is provided for a particular application. Variable methods of control and differences in turn-down ratios means that no two items of plant will have the same operating requirements. As an example, a 900kW chiller manufactured by Carrier requires a minimum system water content of ≈4,600 litres, whereas Airedale manufacture a chiller requiring a water content of only ≈1,350 litres.

BENEFITS

As stated above, terminology used to reference thermal storage vessels is often used interchangeably. For the purpose of this guide, there are two vessel variations:

Buffer Vessel: Used to capture residual heat on shut-down to improve system efficiency

- Dissipate heat from boiler on shutdown
- Protects boiler from overheating
- Improves overall efficiency
- Stored heat can be used by boiler on start-up

Thermal Store: Enables a small boiler to serve a system with a higher capacity

- Boiler can be sized at less than 100% of the system heat demand
- Allows boiler to operate continuously for long periods
- Will serve function of a buffer vessel (takes heat on shut-down and feeds boiler on start-up as required)

Buffer vessels extend the life of plant by preventing short cycling. Short cycling will particularly occur at times of low heat demand when the plant will produce heat at a faster rate than can be used by the system. The system water temperature will therefore rise quickly, shutting down the plant after only a short operating period.

The buffer vessel acts as a store to absorb part of the heat generator (boiler, heat pump, etc.) output when the system load is below the minimum operating output of the plant. This stored heat is then used at the start of the heating period each day when the buffer will discharge in a controlled manner to satisfy part or all of the initial peak heat demand while the central plant heats up. The stored heat can also serve as a preheat to the plant.

A thermal store also provides a heat sink in order that heat pumps can take advantage of lower night time electricity tariffs and possibly lower energy costs (not a clear cut matter).

Used with a CHP, a buffer can provide a thermal store during periods of low heat demand to prevent [waste] heat having to be dumped.

PUBLICATION ADVICE

Information from a collection of published technical sources is detailed in Table 1. Specific guidance is limited in detail, and at best only prescribes rule of thumb parameters. There is no one size fits all solution as system design and use can vary significantly.

Table 1- Information contained in publications

Source	Information Provided
BS EN 14511:2011	Recommends the heat pump should not start more than three times in an hour. This is due to the relatively high starting current of the compressor drive motor and the impact this may have on the local electricity supply infrastructure. Also for the purpose of defrosting, and as a guide, the capacity of the buffer tank should be based on approximately 25 litres per kW output of the heat pump.
BS EN 15450:2007 Design of heat pump heating systems	p.20 (4.5) *"A higher inertia (capacity) can be achieved …by installing a buffer storage (in parallel or series). A buffer storage connected in parallel with the heat pump serves additionally as a means of hydraulic decoupling. A guidance value for sizing the buffer storage volume is 12 to 35 l per kW maximum heat pump capacity"*
BSRIA 7/2009 Heat Pumps (BG7)	p.37 includes statement: "*It [a buffer vessel] is most likely needed for radiator, fan coil and air-handling-based heat distribution systems where the system has limited storage capacity.*" p.38 provides a formula for calculating a buffer volume size based upon minimum operating time. Refer to equation 1. Guidance indicates buffer vessel located in return feed to heat pump.
Energy Saving Trust CE299 (2008), the applicability of district heating for new dwellings	p.15 CHP – "*…thermal storage is normally required to match the heat output of the CHP with the heat demand profile.*" p.20 Biomass – "*Higher levels of biomass penetration will require a greater amount of thermal storage to smooth the heat demand.*"

Carbon Trust CTG012 (2009) Biomass Heating	p.46 "*Where a biomass plant is the only item of heating plant, installing a buffer tank (heat store) can smooth out its running profile*" p.46 "*Seasonal load conditions – ...If the heat load is below the lower limit that the biomass plant can provide (typically 20-30% of the plant rating), this can lead to short-cycling... The inclusion of a heat store can avoid this... ... improving performance and reducing maintenance issues.*" p.41 Batch-fired systems footnote – "*Tank volumes should be at least 40 litres/kW.*" p.47 Biomass plant with buffer tank – "*A useful rule of thumb for sizing the buffer is to allow for 10 litres/kWth plant capacity where loads do not fall to zero, and at least 20 litres/kWth where they do.*"
CIBSE Guide F (2012)	p.4-8 (4.7.3) Biomass Heating – *"...Unless the system demands a constant temperature, a buffer tank may be required."* & also: "*The energy stored in the tank can be used to meet the peak heat demand of the building, thus reducing the required capacity of the boiler*." & also: "*The selection of buffer tank and boiler will therefore depend on the user profile of the building.*" p.8.11 (8.6.2) Chiller control "*adequate system water volume capacity to minimise the number of starts per hour of a compressor (often requiring a buffer vessel)*"
CIBSE AM12 (2013)	p.21 (5.5) Use of thermal storage, lists benefits of thermal storage with CHP. p.22 – "*To establish the optimum size of the store it is necessary to use an hour by hour operating model preferably for the whole year, and to carry out a series of calculations with a range of store sizes.*"
CIBSE KS10 Biomass Heating	p.15 – "*The size of the store will be determined in part by the difference between design flow and return temperatures of the primary circuit. The larger the temperature difference the smaller the store required to hold the same amount of thermal energy.* "
CIBSE TM51 (2013) Ground source heat pump	p.24 (5.3) – "*A buffer tank can be used to provide a reservoir of heat…*" p.25 (5.3) – "*Buffering can be increased by provision of a buffer tank on the return flow*"
Clyde Technical Guide 788/1 (2006)	p.13 The volume of the buffer vessel is dependent on system use and can be calculated from: V (intermittent use) (litre) = heating load (kW) x 25 V (continuous use) (litre) = heating load (kW) x 80 (Spartec, 2006)
DSCF (2007) Biomass for Schools	p.10 (2.8) "*...most biomass boiler systems will work more efficiently if they are installed with a thermal store.*" p.22 – "*…a rule of thumb minimum of 10 L/kW, although for many installations the buffer tank provided is 20 L/kW*".
HVCA TR/30 (2007) Heat Pumps	p.20 – "*...the designer should consider the incorporation of a buffer tank, or buffering volume.*"
HVCA TR/37 (2008) CHP	p.13 – "*Thermal storage (buffer vessels) may be needed to enable operation under low load conditions.*"

INFORMATION REQUIRED

Knowing the following information will assist with the sizing of a thermal storage vessel:

1) Plant details – type of heat source, fuel type and heat output.
2) Heat loads to be supplied – space heating, hot water, process heat, etc.
3) Operating temperatures – flow and return temperatures of primary and secondary circuits
4) Operating patterns for all heat loads – start, stop, number of days, etc.
5) System water content – water in all pipe and heat emitters.

SIZING

There are a number of possible solutions for sizing a buffer vessel, and four methods are provided here. Vessel size will depend upon the application, heat output, fuel quality, minimum acceptable on-time cycle of compressors (ASHP & GSHP), the operating temperature differential of the [vessel] controls, hours of operation, etc. Particular criteria for different sources of heat generation are outline separately below.

Vessels can be large and heavy. For any calculated vessel size, a decision should be made on the viability of the size according to operational needs, installation and maintenance access, available space, weight (including the water), material and installation cost, etc.

The following general definition will determine a vessel size:

Vessel capacity = (required system volume) – (actual system volume)

Where the **required system volume** is that necessary to accommodate the thermal output of the plant and the **actual system volume** is the water volume in all pipework and heat emitters. Plant that has a minimum operating cycle time may require a larger volume than can be accommodated by the pipe system alone. Adding a buffer vessel ensures the system volume is matched to the plant thermal output.

The following sizing methods all adopt the above basic rule with some varying degrees of accuracy.

Method 1 – Rule of Thumb litres per kW

A rough rule of thumb would be to size a vessel volume according to the heating or cooling plant size (see *CAPACITY*) based upon volume per kW. A typical value would be $10L \cdot kW^{-1}$ (the lower limit for biomass).

Method 1 Rule of thumb: 10 litres x Plant size = storage volume (L)

Example: 10 litres x 200kW = ***2,000 litres***

The volume required will vary according to the system design. Refer to notes on different heat sources in this guide for rule of thumb capacities for a range of heat sources. The value used for plant size will also have some variables – see CAPACITY.

Method 2 – Minimum Operating Time

Where a [buffer] vessel is provided to reduce cycling of equipment, the size should be determined by the number of starts per hour. This can be expressed by using equation 1 to define the minimum operating time the plant operates (see BG7/2009).

$$t = \frac{m.c.\Delta T}{Q} \qquad (1)$$

Where:

t	Operating time in seconds (s)
m	Mass of store water (kg) – 1kg = 1L
c	Specific heat capacity of water kJ/kgC
ΔT	Operating temperature differential (°C)
Q	Heat input (kW)

The above formula can be rearranged to find the storage volume (m) as equation 2:

Method 2 Operating Time:

$$\boldsymbol{m = \frac{Q.t\,(x60)}{c.\Delta T}} \qquad (2)$$

Note multiply minutes by 60 to convert to seconds

Selecting a minimum 6 minute runtime (t) would be a good starting point although 10 or 20 minutes may be more desirable.

Example: for an ASHP with a low differential temperature (5°C) operating for a 6 minute cycle

$$m = \frac{75\ x\ 6\ x\ 60}{4.18\ x\ 5} = \mathbf{1,292\ litres}$$

Always refer to manufacturer's instructions as some equipment may have a minimum operating time or advise the number of maximum start-ups (or duty cycles) permitted per hour.

Method 3 – Smallest Zone

Selecting a vessel to meet the demand of the smallest controlled zone ensures there is readily available capacity to at least serve that zone and prevent cycling of a [large] heat source. Selecting the zone with the highest dependency, a north facing zone or area with a high heat loss ratio may be an alternative consideration.

The equation 3 can be used to estimate the required volume of the tank, where:

Method 3 Smallest Zone:

$$\boldsymbol{m = \frac{Qmin - Qzone.t\,(x60)}{c.\Delta T}} \qquad (3)$$

Note multiply minutes by 60 to convert to seconds

Where:

m	Mass of store water (kg) – 1kg = 1L
$Qmin$	Minimum heat output of heat source (kW)*
$Qzone$	Heat demand of smallest zone (kW)
t	Operating time in seconds (s)
c	Specific heat capacity of water kJ/kgC
ΔT	Operating temperature differential (°C)

*Assumes multi-stage or modulating heat source
ΔT = temperature differential tank experiences between heat pump on and off
t = minimum acceptable on time for a heat pump cycle (minutes)

Method 4 – Flow Rate Percentage

A simpler variation on the smallest zone method is to calculate the vessel size based upon a percentage of the heat source flow rate as only a small capacity is accounted for, and no zone heat load information is required.

Typically used for an air source heat pump (ASHP) installation by determining the buffer vessel size to match 10% of the water flow rate of the heat pump/hour for a single compressor unit and 8% for a twin compressor (as the second compressor provides load diversity).

Method 4 Flow Rate Percentage:

Single compressor 10% x water flow rate = storage volume (L)

Twin compressor 8% x water flow rate = storage volume (L)

Example: Twin compressor with a $7.3m^3 \cdot h^{-1}$ water flow rate
Storage volume = 0.08x7.3 = $0.584m^3$ or **584 litres**

CAPACITY

The value used for 'plant size' in *Method 1 – Rule of Thumb litres per kW* will depend upon the system and plant size selection. The plant size could either represent the central plant capacity or the actual connected capacity (load of the heating or cooling emitters).

Where the central plant has redundant capacity (run and standby), the plant size value should normally be equivalent to 100% of the connected capacity. For example, if there are two 100kW boilers each rated at 66% of capacity, then the connected capacity is 132kW (66% of 200kW). In this instance the plant size value used for sizing the buffer vessel should normally be 132kW, but could of course be taken as 200kW in some circumstances. Which figure is used will depend upon the method used to size the plant as well as the plant control arrangement and thermal inertia characteristics of the building.

Remember the general rule: **Vessel capacity = (required system volume) – (actual system volume)**

STORED ENERGY

Occasionally the energy storage capacity of a vessel will be quoted. This actually depends upon the operating conditions of the system. By way of example, using equation 4, the heat energy can be calculated for a 1,500 litre vessel with a flow and return temperature of 80°C and 50°C respectively as shown below.

$$\boldsymbol{Q} = \frac{\boldsymbol{m.c.\Delta T}}{\boldsymbol{3600}} \quad (4)$$

Heat capacity in 1,500 litre vessel with 80°C flow and 50°C return:

$$Q = \frac{1500x4.18x(80-50)}{3600} = \mathbf{52.25kWh}$$

ASHP

A buffer is essential for air source heat pumps (ASHP) as it provides the energy for the defrosting at low external temperatures. Air source heat pumps will defrost the evaporator to remove ice build-up at low ambient temperatures, usually by switching into a reverse cycle operation. During this cycle the condenser temporarily becomes the evaporator and heat is removed from the heat sink starving the building heat system.

In addition to this the performance of an ASHP will fall when the ambient temperature drops, whilst at the same time the property heat demand increases. So both efficiency and heat output of an ASHP will decrease at colder times of the year. In the UK, the normal diurnal temperature swing would permit operation of the ASHP to heat a thermal storage vessel during the day when the system demand falls, providing a ready supply of heat for when demand rises and the ASHP performance drops off. Of course this is all subject to assessing load patterns, and it is common to utilise a back-up boiler with ASHP to cope with peak demand.

Typical manufacturer recommendations for a buffer vessel with an ASHP are:

1) Size at 10% of the heating water flow rate of the heat pump per hour.
2) A volume of approximately 8% is sufficient for heat pumps with two performance levels.
3) Limit to less than 30% of the heating water flow rate per hour.

BS EN 15450:2007 suggests **sizing the buffer storage volume at 12 to 35 L per kW maximum heat pump capacity**.

Oversized buffer vessels lead to longer compressor run times which will be particularly detrimental in systems with two performance levels where a large store capacity may lead to the unnecessary switching on of the second compressor.

BIOMASS

A rule of thumb for biomass is: **size vessel between 10 and 20 litres/kWth plant capacity** (CTG012, p.47); a lower value may be used where loads do not fall to zero, for pellet fuelled boilers which are more responsive and for boilers with a low turndown capability.

Where low grade wood with high moisture content is used, the storage volume may need to be sized at up to 40 litres/kWth or more.

A buffer vessel for use with biomass boilers must be sized for the specific type of boiler burning a particular fuel. An undersized buffer will cause the following conditions:

1) Fail to capture sufficient heat from the boiler on shutdown, resulting in inefficient boiler operation.
2) Short cycling of the boiler when supplying loads lower than its minimum output.
3) Will be unable to supplement the boiler output adequately to meet peak heat demands.

For the above reasons always consult with the boiler manufacturer.

CHILLED WATER

Chillers should not usually exceed six starts per hour; some manufacturers suggest on three starts. Therefore, capacity is required to ensure the distribution volume size is adequate to accommodate the chiller thermal input. A rule of thumb should therefore be: allow 10 or even 20 minutes minimum operating time (see calculation Method 2).

A rule of thumb is to size in the range 2.5 to 8 litres per kW for most cooling applications and a higher 8 to 14 litres per kW when temperature accuracy is critical.

Another rule of thumb is to size a buffer vessel according to the system use: **a minimum of 4 litres/kW for air conditioning and a minimum of 7 litres/kW for process cooling**.

Manufacturers may quote a minimum system water volume based upon the plant turndown capacity.

Tanks used with chilled water should be baffled to ensure there is no stratification and that all fluid in the tank is adequately mixed.

CHP

Sizing buffer vessels for combined heat and power (CHP) systems is much more complicated. As stated in CIBSE AM12 "*To establish the optimum size of the store it is necessary to use an hour by hour operating model preferably for the whole year, and to carry out a series of calculations with a range of store sizes*". It is suggested expert advice is sought when designing a CHP installation.

GSHP

According to Clyde, the volume of a buffer vessel is dependent on system use and can be calculated from:

V (intermittent use) (litre) = heating load (kW) x 25
V (continuous use) (litre) = heating load (kW) x 80

The CIBSE TM51 (2013, p.24) details the implementation of buffer vessels but does not provide any sizing guidance. It does however provide this cautionary comment:

"[buffer vessels] adds cost, requires space and there is a loss of efficiency due to additional heat barrier with indirect systems. The buffer tank can be eliminated if there is sufficient buffering in the heat emitter water circuit".

Another consideration is that there is unlikely to be sufficient capacity in a modern well insulated building with small heat emitters.

HEAT PUMPS

See both ASHP and GSHP. BS EN 14511 recommends for a heat pump not to start more than three times in an hour. This is due to the relatively high starting current of the compressor drive motor and the impact this may have on the local electricity supply infrastructure; starting current is normally reduced with inverter controlled compressors.

BS EN 14511 recommends for the purpose of defrosting, and as a guide, **a buffer tank should be sized on approximately 25 litres per kW output of the heat pump**.

SOLAR THERMAL

Solar thermal systems for the production of hot water are often complex with multiple heat sources. Thermal stores usually provide indirectly pre-heated water to the domestic hot water system and their size may be dependent upon both the property heat requirements and domestic hot water consumption. Storage capacity for domestic water only should maximise the solar gain and be matched to the demand.

LOCATION OF VESSEL

The location of the vessel that achieves optimum performance will depend on the system. Typically, buffer tanks are used with heat pump systems and thermal stores with biomass boilers.

For fastest response, a buffer vessel should be positioned in the return pipework to the heat pump (see Figure 1) as heat will always be delivered to the system first. However, where a vessel is used to preheat domestic hot water it should be installed in the flow from the heat pump.

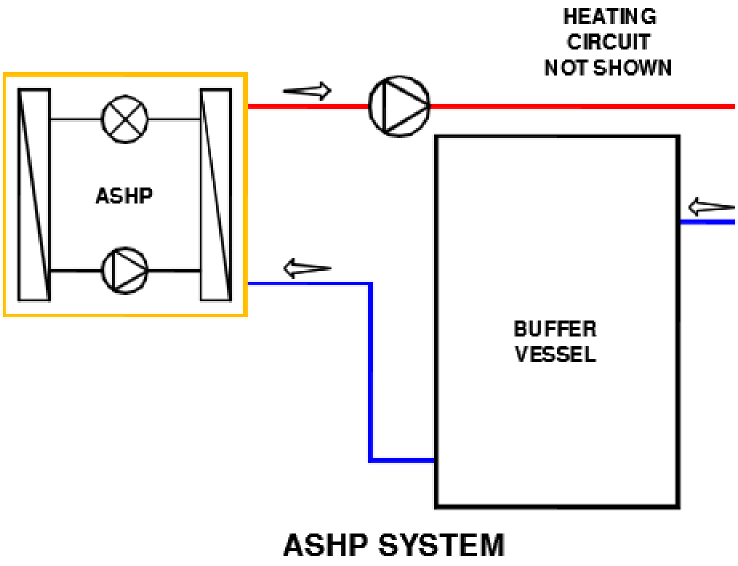

Figure 1 - Buffer vessel used with an ASHP

As biomass boilers usually have a long heat-up period, thermal store vessel arrangements are favoured as illustrated in Figure 2. Thermal layering is a necessity in this arrangement (see STRATIFICATION).

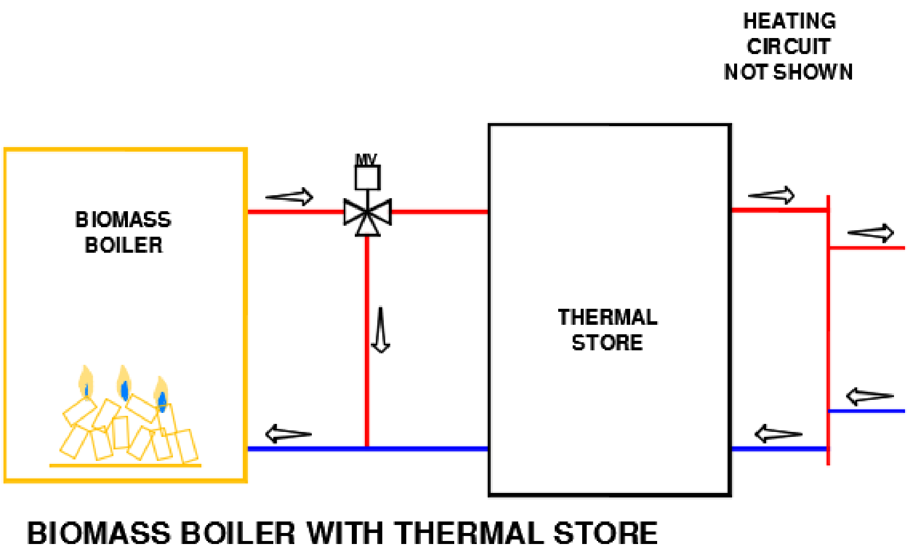

Figure 2 - Thermal store with a biomass boiler

CONTROL

A high level temperature sensor in a buffer vessel can be used to switch-off the heat source and a low level sensor switch the heat source on when the stored temperature drops. Sensors at intermediate levels permit plant modulation control.

A thermal store used with a biomass boiler will include a 3-port valve. This prevents cooler water returning directly to the boiler from the base of the accumulator and avoids condensation (that can cause boiler corrosion) in the boiler. As a biomass boiler increases in temperature the valve will slow open to permit circulation through the vessel.

STRATIFICATION

Thermal stores, as used with biomass boilers, rely on temperature stratification or thermal layering to work effectively. This results in a high temperature at the top of the vessel than at the bottom. As hot water is lighter (80°C water density 972kg·m^{-3}) than cold water (20°C water density 998.3Kg·m^{-3}), the hot water will stay at the top of the tank, and the cooler water at the bottom. Turbulence can disturb this stratification affecting efficiency, therefore high water flowrates through a vessel must be avoided. Multiple energy sources, which may operate at different temperatures, connecting to a thermal store can also cause disruption to the stratification.

The thermal layering effect is shown in Figure 3. This works because of the four pipe connections. Heated water from the boiler flows through the top of the storage vessel at peak demand, providing the system with high temperature water. As the system demand falls, the overall temperature of the store will rise, with the hot layer slowly moving down to replace the cooler layer as the boiler satisfies the diminishing demand. Of course, this will not happen without control that regulates demand on both the primary and secondary side of the thermal store.

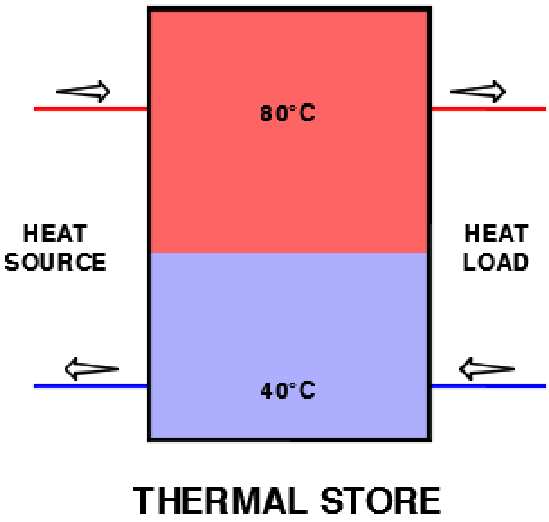

Figure 3 - Thermal layering in a thermal store

However, mixing is desirable where a buffer vessel is installed in-line and with plant operating to a small temperature differential (such as heat pumps), so stratification should be avoided.

With heat pumps this mixing ensures the circulation temperature returning to the heat pump is not above the heat pump maximum, preventing the heat pump from operating. Buffer vessels, particularly large volumes, used in such systems may contain a baffle plate (see Figure 4) that prevents short-circuiting between the piped inlet and outlet to promote good mixing within the vessel.

The position of the inlet and outlet is also important to promote mixing and ensure the return water to the heat source is the lower system return temperature.

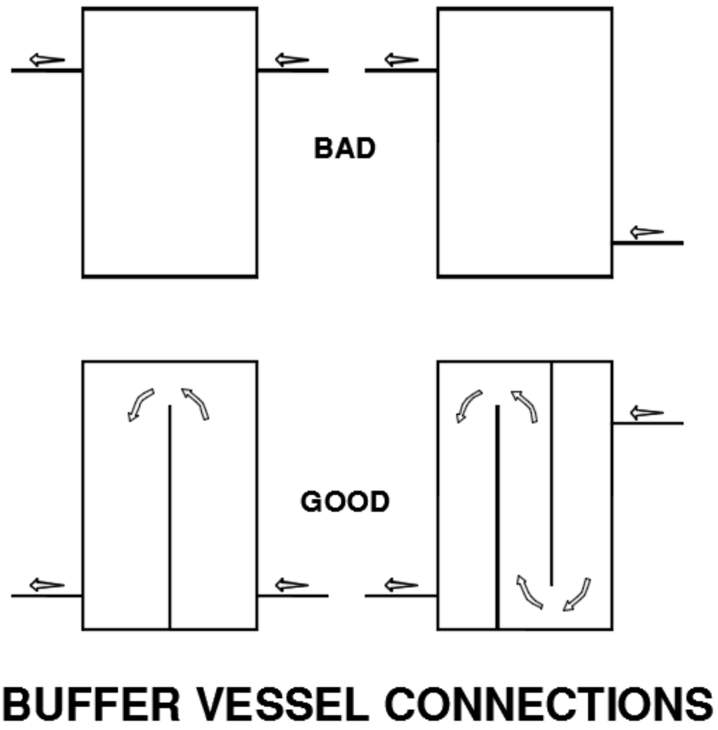

Figure 4 - Mixing in a buffer vessel

ISSUES

There are many precautions that should be observed to ensure a heating or cooling system with a buffer vessel is safe, controllable, energy efficient and effective at delivering thermal comfort.

An undersized buffer vessel will not capture sufficient heat from the central plant on shutdown, resulting in inefficient operation. Also an undersized buffer will not adequately supplement the plant output to meet peak load demands.

An oversized boiler attempting to meet a load less than its minimum output without a buffer vessel, or with an undersized buffer vessel, will operate by constantly switching on and off, resulting in under-temperature operation of the plant, inefficient combustion and excessive emissions of pollutants.

For biomass, the size of the buffer vessel will be dependent upon the fuel quality – the lower the grade of wood (higher the moisture content) the larger the vessel required. Conversely, a vessel should not be oversized with good quality pellet fuel.

Systems with large temperature differentials will only require a small thermal store, however low return temperatures can lead to condensation issues with flue gases which should be avoided with biomass.

DEFINITIONS

Accumulator Tank	A buffer vessel or thermal store.
ASHP	Air Source Heat Pump.
Auxiliary Boiler	A boiler, usually fossil fuel, which assists the primary (ASHP, biomass, CHP, etc.) system to meet the peak load. As peak load is infrequent, a biomass boiler sized to meet the base load can be installed to provide a large capital saving. The auxiliary boiler is sized at the difference between the base and peak load.
Back-Up Boiler	A second boiler, usually fossil fuel, used to provide 100% back-up to the primary (ASHP, biomass, CHP, etc.) system.
Base load	The minimum heat demand from a system which is maintained throughout a defined period.
Biomass	[Renewable] organic materials, such as wood, agricultural crops or wastes
Bivalent systems	Heat is generated by two separate means, using the two heat generators as alternative heat providers. The low carbon (or higher efficiency) heat source is the primary heat generator and a second heat generator (see auxiliary boiler) is provided to satisfy peak load. Often the second heat source will be sized at 100% to serve as a back-up.
Buffer tank or vessel	A vessel that captures residual heat on boiler shut-down preventing frequent boiler start-ups to improve system efficiency. A buffer effectively prevents cycling of the boiler when the system demand is less than the boiler minimum output. Buffer vessels are therefore used with ASHP's & GSHP's to reduce compressor starts. The additional capacity will also reduce the energy required from an auxiliary boiler. Usually has a simple on/off control strategy.
GSHP	Ground Source Heat Pump.
Heat Pump	A device which moves heat energy from one place to another while raising it from a lower to a higher temperature.
kW_{th}	Kilowatts of thermal energy.
Short Cycling	Short cycling occurs if the heat source turns on and off within a short period of time. Can cause electrical fault in a heat pump or fuel blockage in a biomass boiler.
Thermal Store	A vessel that is charged by the primary (ASHP, biomass, CHP, etc.) system when the heat generator output exceeds the load demand. This, for example, enables a small biomass boiler to meet a larger demand. A progressive control strategy using several temperature sensors will control the boiler output – may not be possible with heat pumps.
Turndown Ratio	The ratio of maximum to minimum operating capacity (the boiler or chiller high to low output). For example, a 100kW system with a 4:1 turndown would provide 25kW at minimum operating capacity.
Water Storage Cylinder	A vessel storing water to be used as an accumulator, buffer vessel or thermal store.

SPECIFIC HEAT CAPACITY

The specific heat capacity (*c*) value 4.18kJ·kg^{-1}·K has been used in calculations in this document for convenience. Specific heat capacity values for a range of temperatures are recorded below.

Table 2- Water specific heat capacity

Temperature (°C)	Specific Heat Capacity (kJ·kg^{-1}·K)
10	4.193
20	4.183
30	4.179
40	4.179
50	4.182
60	4.185

CONVERSIONS & DATA

The following conversions and data may be useful.

Centigrade to Fahrenheit: F = (Cx9÷5) +32
Fahrenheit to Centigrade: C = (F-32) x5 ÷9
1 Litre = 0.21996915 Gallons (UK)
1 gallon = 4.54609 litres
1 Gallon of water is equal to 8.33 Pounds
1 Litre of water is equivalent to 1 Kilogram
1 cubic metre of water is 1,000 litres (1m^3 = 1,000L)
1 kg = 2.2046 lb
1 lb = 0.4536 kg
1 KW = 3412 BTU/hr
1 BTU/hr = 0.2931 Watts
1 refrigeration ton = 3.5168525 kW
1 kilowatt = 0.284345 refrigeration ton
1 bar = 100 kPa = 10.1972 m.$H_2$0 = 14.5037 lb/in^2
1m^3 = 35.3146667ft^3
1ft^3 = 0.02831685m^3
1 sq.yd = 0.836m^2
1m^2 = 1.196 sq.yd

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