# EndoTherm®

# HYDRONIC HEATING SYSTEM ADDITIVE: HOW IT WORKS

## Technical Summary - v1.3


**Dr Andrew Williams holds a first class Masters degree in Mechanical Engineering and PhD from Loughborough University. Dr Williams has been an active researcher in the areas of energy and thermofluids since 2001, including co-leading a UK Fluids Network Special Interest Group and academic advisor for the Energy Technologies Institute.**

**In roles as Senior Lecturer at Loughborough University and Visiting Research Fellow at University of Chester he applied his expertise in energy and thermofluids to the challenge of heating system de-carbonisation and hydronic heating system additives.**

**Hydronic additives can be used to manipulate a wide variety of heat transfer related parameters. Some of these parameters can be used to increase or reduce the local heat transfer coefficients while others can be used to change the amount of thermal energy the fluid holds.**

**The impact of EndoTherm on heating systems is more complex than a single cause and effect due to the interactions between local heat transfer, heat capacities, flow behaviours and the environment.**

Complex fluids such as EndoTherm have thermo-physical properties which are dependent not only on the bulk mixture but also the often transient thermal and physical conditions the EndoTherm dosed fluid is experiencing.

The formulation of EndoTherm has been developed to improve the delivery of heat where and when it is needed. This is achieved by the cumulative effect of interactions between the fluid, the heating circuit and the control systems.

Although the exact combination of effects is proprietary, we are leveraging the following effects to different degrees, depending on the system:

1. **Reduced Specific Heat Capacity.**
   The working fluid acts as a carrier for thermal energy, between the heat source and the heat emitter. It is the temperature of the fluid which drives the flow of heat.

   A fluid with a lower specific heat capacity has less embedded energy for a given temperature, thereby contributing to increased thermal responsiveness of the fluid and heat emitters, as well as less excess heating once demand has subsided.

   EndoTherm's specific heat capacity is made more complex in unsteady scenarios where a more thorough thermodynamic approach to internal energy analysis is required that can cope with the transient state of the water's hydrogen bonding network.

2. **Increased Surface Wetting and Reduced Surface Bubble Formation.**
Absorption and degassing behaviour is significantly changed with the addition of EndoTherm. This tends to keep surfaces bubble-free and significantly more wetted.

   Where surface bubbles already exist, they are more likely to be removed from the surface when disturbed, for example under flow. In components where such surface vapour occurs, this can lead to improved rates of heat transfer and improved component performance.

3. **Increased Rates of Two-Phase Heat Transfer.**
The lower surface tension allows more frequent departure of smaller bubbles when boiling heat transfer is taking place, enhancing the near surface mixing and significantly increasing rates of heat transfer for a given surface temperature.

4. **Reduced Effective Viscosity.**
The rheology of the fluid affects the internal mixing, impacting on the pressure drops and flow rates through the pipes as well as heat transfer. EndoTherm can reduce the viscosity of the fluid resulting in changes to the flow rates and pumping work required.

5. **Temperature Dependent Bi-phasic Behaviour.**
The behaviour of micelles within EndoTherm can interact with ions within the water at particular temperatures, with associated changes in rheology and thermo-physical characteristics.

## Hydronic Heating Systems

Heating systems often rely on water circuits to move the heat or cold between the source (boiler, heat pump or chiller) and the occupied spaces. When heat or cold is demanded in the occupied spaces, the system attempts to match the supply and demand by controlling the source heat or cold input to the circulating water.

In situations where demand and conditions are constant, modern thermostat controls can effectively match the supply to demand. However, such constant demand and constant external conditions do not exist in real applications.

The demand for heat from a heating system to maintain a given temperature is the difference between the heat loss and the heat generated within any space. Sources of heat generation include people, equipment and solar gains. Such heat generation can vary in magnitude by hundreds of watts in a matter of minutes. Therefore the true heat demand from the heating system also varies over the same time-scales.

The amount of cooling required by chiller circuits is equally unsteady as the heat generated within a space varies throughout a day.

The path of heat or cold from the source through the hydronic circuit to the room is significantly slowed down by the hydronic circuit, limiting its ability to respond efficiently and effectively to changes in demand, both increases and decreases. To achieve comfortable rooms with this lag inherent in the hydronic circuit, it is inevitable that we end up delivering some heat or cold at the wrong-time and wrong place within the buildings.

The amount of energy used to heat our buildings is therefore higher than the minimum needed to maintain comfortable space temperatures. Existing heating systems can better match supply with changing demand if the hydronic circuit can respond more quickly without using more energy to do so.

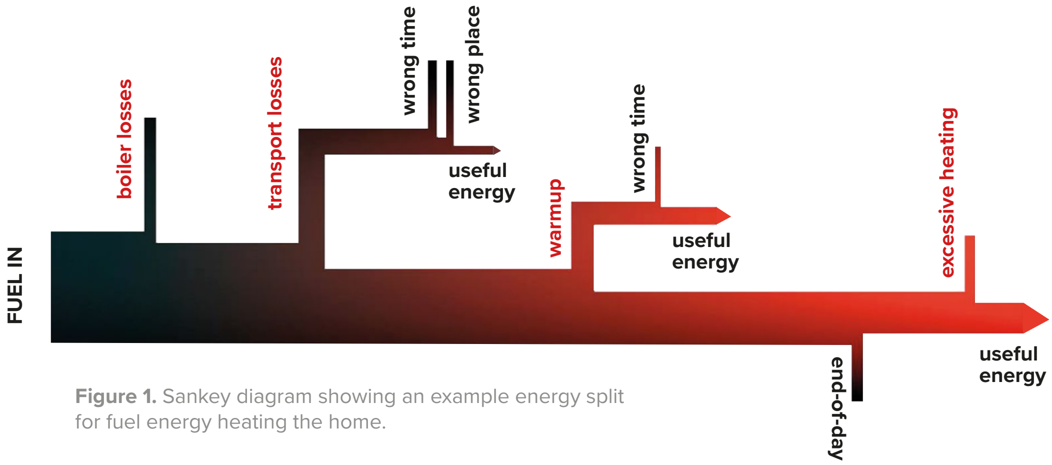


**Figure 1.** Sankey diagram showing an example energy split for fuel energy heating the home.

The Sankey diagram in Figure 1 above shows example energy split in a domestic property's heating system and the contributing factors to wrong-time and wrong-place heat delivery.

The boilers are typically efficient at converting chemical energy into thermal energy within the water. Some of this energy is lost through the pipe distribution network. Such transport losses may contribute to useful heating but some will be delivered at the wrong-time and wrong-place contributing to wasteful heating.

A significant amount of energy is used get the building up to temperature after a set-back period. This is required energy and is therefore considered mostly useful. The rate at which the rooms can be brought up to temperature does however impact on how long the heating system is on for and therefore does influence the amount of wrong-time heat delivery.

Due to the inherent difficulties matching supply and demand with current control systems, there is an amount of wasteful excessive heating where rooms are heating above their minimum comfortable temperature. At the end of any heating period, the amount of embedded energy in the heating system affects the amount of wasted energy.

## EndoTherm Effects in Heating Systems

The most significant system level effect of EndoTherm in the majority of heating systems is the improved ability of the system to efficiently respond to changes in demand, both increasing and decreasing.

Demand is fundamentally unsteady in heating systems because of solar cycles, heat generation and occupant behaviours. Controls in heating systems attempt to efficiently supply enough heating to meet the demand. The responsiveness of the hydronic circuit is a major limiting factor in the ability of the system to match supply of heat with the changing demand, leading to wrong-time and wrong-place heat delivery, ultimately leading to wasted energy. This limitation of the control systems is present even with more complex controls such as PID controls.

We have amassed over 200 field trials, most of which are independently led. Many of these are on heating systems but a growing number showing excellent results on cooling systems. Although a single positive result from one field trial in isolation may happen because of other factors, the probability of achieving the vast amount of positive field trial results we have seen with EndoTherm arising from anything other than the EndoTherm effect is small.

Field trials remain therefore an excellent approach to evaluate the cumulative effect of all these complex and interacting real world behaviours on heating system energy consumption. Studies to isolate specific parts of the EndoTherm effects have given much insight to explain these real world energy savings.

## EndoTherm Effects in Heating Systems continued

Testing in the 2010 BRE Exemplar test house at Liverpool John Moores University with condensing boiler and balanced radiators showed ~25% increase in rate of heating of the water from the boiler and water delivered to the radiators alongside ~6% increase in rate of cooling of the water when demand is met.

These effects arise because of the combined rheological behaviours, the reduced specific heat capacity and the enhanced two phase heat transfer.

Independent laboratory testing based on a thermostatically controlled thermal enclosure heating by a condensing gas boiler showed increased rates of water heating of ~10% alongside energy savings of up to 15%.

**Figure 2.** 2010 BRE Exemplar Houses used for testing at Liverpool John Moores University

Building and room simulation studies that properly represent the hydronic circuit and demand unsteadiness show a significant energy saving opportunity from the modest changes to fluid specific heat capacity that EndoTherm offers. These savings are before the improved heating responsiveness is considered.

Many models cannot capture these effects as they overly approximate or ignore the unsteadiness in the building and heating system. The highly non-linear relationship between demand unsteadiness and daily energy consumption means many different scenarios need to be simulated to give an indicative energy saving, which is no small task. Simulation studies are ongoing with our research partners to improve our simulation capabilities in terms of fidelity and computational efficiency.

Enertek International

Direct comparison tests with and without EndoTherm indicates that **the gas consumption of the boiler in a heating system can be reduced by up to 15% with EndoTherm.**

The empirical evidence indicates that the addition of EndoTherm can significantly reduce space heating gas consumption and therefore $CO_2$e emissions.

University of Chester
LIVERPOOL JOHN MOORES UNIVERSITY

In partnership with University of Chester and Liverpool John Moores University, researchers are experimentally quantifying, to much higher accuracy than ever before, the fluid behaviour changes caused by EndoTherm, and are exploring through simulation the impacts of these changes on building and heating system behaviour.

uclan

The recorded gas consumption from tests was compared and results showed that **systems dosed with EndoTherm consumed 10.4% less gas than systems containing only water.**

UNIVERSITY OF THE WEST *of* SCOTLAND
UWS

**EndoTherm achieved a 19.2% improvement in thermal responsiveness during heating and cooling experiments due to a combination of specific heat capacity and heat transfer changes.** Testing also showed EndoTherm liberated this thermal energy much quicker through an improvement in heat transfer.

## Frequently Asked Technical Questions

**Q If the dose rate is only 1%, how can you have such a disproportionately large influence on the fluid properties and building behaviour?**

A Dosing water with EndoTherm does not create a simple mixture. The molecules interact with the hydrogen bonding network within the water which is responsible for many of water's properties. By designing the molecular behaviour of EndoTherm in water, or more specifically how the molecules interact as temperature changes, we can achieve much bigger changes to important properties than would be achieved by a simple mixture.

**Q How can fluid properties depend on the temperature history and unsteadiness?**

A The interaction between the EndoTherm molecules and the hydrogen bonding network, which is causing important changes in fluid properties, depends on the distribution and state of the molecules within the water. If left for long enough, the mixture will reach its equilibrium state where some molecules are within the water as individual molecules whilst others are clustered together in micelles.

The interaction with the hydrogen bonding network is different in these two conditions. If the fluid was being heated or cooled, the amount of free molecules in that region will change very quickly leading to a depletion or excess of free molecules. This causes concentration gradients and an effective diffusion of molecules and micelles towards the new equilibrium state.

This takes some time and as a result, during unsteady thermal processes parts of the system are often at non-equilibrium conditions with respect to EndoTherm molecular distribution. The result is an interaction with the hydrogen bonding network which can be different due to different temperature history and surroundings conditions, even if the temperature is the same.

**Q Can small changes to fluid properties really lead to significant energy savings?**

A Yes, the way heating systems deliver heat is affected by the thermal-dynamic and flow behaviour of the hydronic network, which is affected by fluid properties.

The relationship between fluid properties and energy consumption is very non-linear, meaning small changes can have a relatively large effect. This is most easily seen when modelling thermal-dynamic behaviour of a room or building, which we are actively exploring and quantify with research partners.

What may seem like small changes to fluid properties improves the way the whole system can operate resulting in better matching of supply and demand as well as less wastage of energy by minimising wrong-time and wrong place energy transfer.

**Q People have said that the large thermal mass of the building means that any wrong-time energy means less energy is needed later in the day. Doesn't that mean it is useful?**

A Not entirely. When studying the thermal-dynamic behaviour of a building in sufficient detail one realises that the rate of heat loss from the building also increases as a result of wrong-time energy delivery.

It is true that the increase in building fabric temperature reduces the energy needed in the next heating event, but the amount of energy saved is always less than the amount of energy used because of the increase in building heat loss which is also occurring.

The fraction of wrong-time energy which is wasted depends on the specific scenario, but detailed modelling is showing that it certainly is significant.

## Frequently Asked Technical Questions continued

**Q** **If our building has a very steady heat demand, does this mean EndoTherm won't give an energy saving?**

**A** It is highly unusual to come across a building with a very steady heat demand due to the influence of occupant behaviours, boiler and system controls and other heat sources. The few exceptions are when the outside temperature is particularly cold and steady, solar irradiance is negligible and insulation levels are ineffective resulting in a very high and steady loads.

In these unusual scenarios, where there is still some degree of unsteadiness, testing indicates smaller savings of the order of 5%.

In the vast majority of buildings, there is significant unsteadiness which may often be unrecognised by the building management teams, and the savings are more often in the range of 10-20%.

**Q** **How can I best predict the energy saving I will get in my building(s)?**

**A** The industry has developed a range of methods to try to help people and organisations predict heating system saving potentials. To deliver tools which are tractable they inevitably simplify the problem trying to capture the main effects. Unfortunately this almost always includes simplification of the unsteady behaviour of the buildings meaning that they cannot inherently predict the savings potential of EndoTherm. Instead, more detailed physics based modelling of the buildings is required with representative unsteady heat demands and loads.

We have tools capable of doing this but the time and resource required to gather accurate input data for the models makes it a second best option. Reduced versions of these models are on our R&D roadmap but are not yet available.

Many clients have historically opted to run field trials instead, which ensures that their buildings, control approaches and occupant behaviours are properly represented. This has resulted in a large database of field trial data across different types of buildings, building uses, climates and energy sources. The amount of this data can, in common scenarios, negate the need for further trials. We can help you identify a subset of field trial data which is most representative of your target building portfolio to give a reasonable indication of expected savings.

**Q** **Doesn't reducing the specific heat capacity reduce the ability of the system to deliver heat, thereby restricting the system performance?**

**A** Not noticeably with the changes caused by EndoTherm. The relationship between specific heat capacity and heat delivery is indirect. The ability of heat emitters such as radiators to deliver heat is determined by their temperature. During periods of high demand, the radiator temperatures are not significantly affected by small changes in fluid heat capacity, as the feed temperature will still be controlled by the boiler. The return temperature will be slightly lower, but this has a relatively small influence on the mean temperature difference between the radiator and the room.

For example, a radiator being fed with water at 60°C may result in a return temperature of 50°C with water and 49.5°C with EndoTherm. The amount of heat that this radiator can deliver drops in this case by only 0.7% which is negligible. On the boiler side, the lower heat capacity and slightly lower return temperature means that the boiler is more than capable of putting the energy back in to reach the 60°C again.

Other products that have much larger drops in specific heat capacity alongside, for example, significant increases in viscosity will affect the heat transfer potential of the heat emitters more significantly and are therefore not desirable.