Energy Audit Standard for Process Heat Systems

A standard for the auditing of the energy efficiency of direct and indirect heating systems

Version 1.0

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Contents

0.0 Purpose Statement

This Audit Standard ("Audit Standard") for Process Heat Systems is provided by the Energy Efficiency and Conservation Authority (EECA), for the purpose of providing a quality 'whole-system' auditing methodology for process heat systems in common use in New Zealand industry.

It is expected that, when used by suitably qualified parties, adherence to this Audit Standard will provide the procurer of the audit with confidence that the services received are of high quality.

0.1 Process Heat Systems Audit Standard

The Audit Standard is designed to guide the collection and analysis of heating system data for the purpose of identifying opportunities for improving the system's energy efficiency and providing relevant technically and commercially sound recommendations.

The Audit Standard is technology-neutral and measurement-method neutral, although the measurement methods used will be important in the context of the scope and measurement accuracy required of an audit.

0.2 Disclaimer

As owner of this Audit Standard, EECA will exercise due care in ensuring that it is maintained as fit for purpose.

However, EECA accepts no responsibility or liability for any direct or consequential loss or damage resulting from, or connected with, the use of this Audit Standard by any party.

Further, this Audit Standard does not seek to represent the obligations of any parties entering into any agreement for services relating to a heating system audit.

0.3 Further information

EECA has commissioned the Energy Management Association of New Zealand (EMANZ) to maintain this Audit Standard, in conjunction with relevant industry stakeholders.

If you have questions in relation to this Audit Standard, you may email info@emanz.org.nz , including reference 'PH Audit Standard' in the subject line. You may request to be notified when a new version is created.

The current version of the Audit Standard and other relevant information is available by visiting www.emanz.org.nz.

1.0 Overview of the Process Heat Systems Audit Standard

Process Heat systems are used extensively to provide heating for various industrial processes — essential to the daily operation of many companies. Such systems include indirect-heating steam boiler and hot water generator systems, as well as direct-heating systems such as gas-fired drying ovens.

This Audit Standard provides an approach to heating system auditing and analysis. The objectives of the standard are to:

a) provide the framework for the systematic collection of data relevant to the efficient operation of heating systems; and
b) enable the heating system auditor to analyse the performance of the system, identify potential energy savings and provide sound recommendations for implementation of energy efficiency initiatives.

In addition, Appendix 7 includes a recommended report outline for the purpose of assisting concise, consistent and complete presentation of the analysis, findings and recommendations arising from a Process Heat system audit.

1.1 Scope of the Audit Standard

The scope of the Audit Standard is direct or indirect industrial heating systems, including distributed systems such as air, high-temperature fluids (e.g. thermal oil), steam and hot water systems, as well as direct process heating systems. Section 3.0 covers the on-site measurement requirements of an audit, while Section 4.0 covers the data analysis expected to assess the performance of heating systems.

Assessing the efficiency of a heating system amounts to assessing the system's efficiency in *fulfilling the purpose that the heating process is serving.*

The boundary of the system concerned extends from the energy input to the heating system, whether via burning of a fuel or consuming electricity, to the point where the business purpose of generating the heat is achieved.

For example, that business purpose may be to provide heat for a cooking process (in the case of an oven) or to provide heat for a drying process (such as in the case of a lumber kiln) or to induce a chemical reaction. It is important to understand the ultimate goal of a process to ensure that any potential system changes are compatible.

The system boundary is therefore defined by the points beyond which any change to the system no longer has any effect on the business purpose that the system is serving. Figure 1 shows the components within a typical system boundary, in this case a steam heating system.

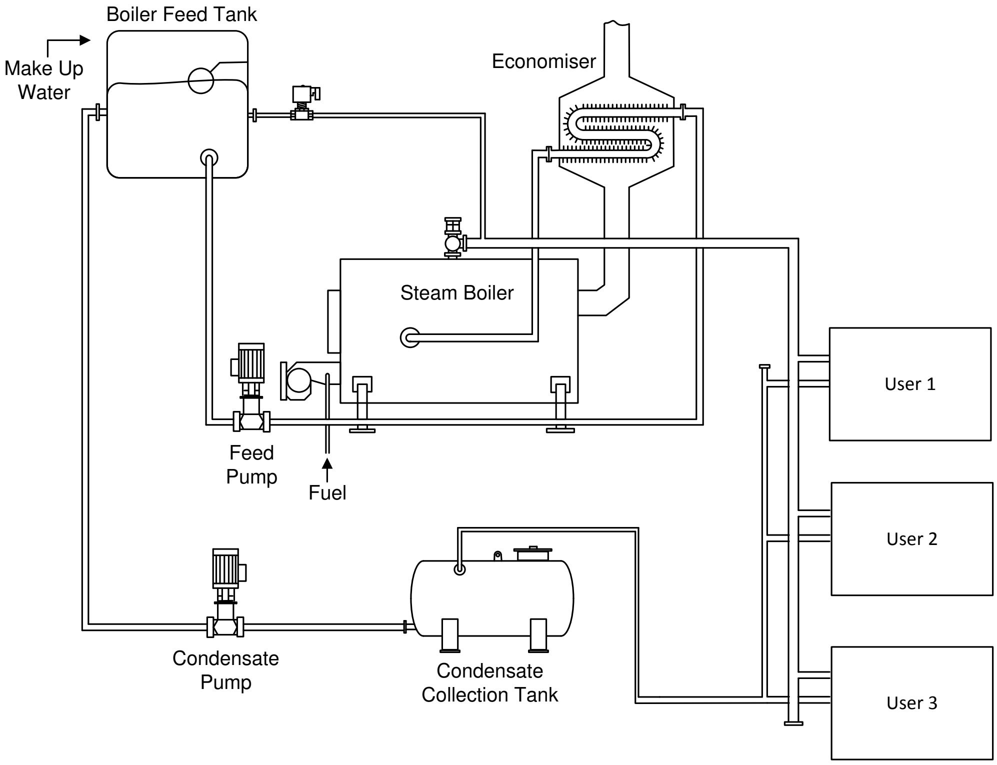

Figure 1: Heating System Boundary (e.g. Steam)

1.2 Accuracy and Measurement

This Audit Standard includes guidance on the expectations of audits conducted according to two generalised levels of accuracy requirements — a ‘base level’ and an ‘investment level’. These levels are representative of the two ends of an accuracy requirement continuum. Where on that continuum the audit fits is a matter for agreement between the auditor and the client, and will be determined by the client’s purpose in commissioning the audit.

The implications of measurement accuracy on audit accuracy are described in Appendix 4.

The measurement and analysis applicable for an audit primarily intended to identify areas of inefficiency and opportunity in the system (a typical base-level audit) generally does not include extensive use of flow, pressure, temperature, fuel consumption and power measurement equipment.

A base-level audit may be the appropriate level to use to define the scope and measurement requirements of a subsequent investment-level audit of the same system.

While the Audit Standard does not specifically cover the skills required of the auditing party, the accuracy level requirement of the audit will have an effect on the level and scope of the skills required of the auditor.

2.0 Planning the Audit

2.1 Audit Objectives and Scope

Consulting with the client to identify and record the client's objectives in having the audit performed is a critical prelude to defining the scope of the audit and the associated measurement requirements.

An audit for a client who is seeking merely to understand where the heating system's efficiency opportunities exist in a factory may have lesser scope and measurement requirements than one that is required for a client who needs the audit findings as input into a capital investment proposal.

Agreement on objectives and scope should also include agreement on the content and structure of the audit report for subsequent presentation to, and discussion with, the client.

AS/NZS 3598:2000 should be used to guide expectations for both the client and the audit team in terms of what is expected from the audit and required of the audit team.

2.2 Business Context

The business context of the heating system(s) to be audited, or what is required of the system(s) in the wider business operation, needs to be established in order to define the measurement requirements for the audit and any post-implementation phase.

If (as is generally the case) one of the purposes of the audit is to provide information that will identify ways to improve the efficiency of the heating system, then the requirement of the system, and what is driving that requirement, must be understood from the outset. This is important for useful post-implementation monitoring of the heating system's energy performance.

For example, the requirement of a steam system may be to supply steam under pressure for an autoclave to sterilise product. The efficiency of this system (from an energy perspective) will be maximised by minimising the amount of energy used to deliver that requirement (sterilise the product). There may be an alternative solution to using an autoclave altogether, being more energy efficient and not requiring a steam system. This highlights the importance of viewing the system as a whole rather than focusing on the heat generation side.

When planning the audit, the relationship between the output of the heating system (and therefore the energy input to the system) and the business driver of the heating system should be identified. The driver may be measured through one of a range of factors, such as hours of operation, production input (e.g. daily kg of material), production output (e.g. daily kg of product) or other measures such as ambient temperature (e.g. daily average temperature).

2.3 Resources and Responsibilities

2.3.1 Resource Requirements

The audit scope and accuracy requirement agreed with the client will determine the people and other resources required to perform the audit. The audit quotation presented to the client (which will form the basis of the service agreement subsequently established with the client) needs to include an assessment of the resource requirements.

The general expectation is that investment-level audits typically require more significant amounts of data collection, measurement equipment use and skilled people time than a base-level audit. However, a lower-level audit does not mean a lower level of auditor competence; the less firm the data, the more pressure on auditor experience for correct interpretation of observations. Where there are industry-specific or any other unique system functions or physical variables, care should be taken by the auditor to work only within their level of professional competency.

2.3.2 Audit Functions and Responsibilities

The audit requires ‘management’ and ‘expediting’ functions to be performed and, where an audit team is involved, it requires an allocation of the various audit responsibilities. The functions included within each of those areas are as follows:

Audit Managing: to ensure that the audit overall is managed to deliver a quality output, on schedule. This includes ensuring that:

a. the audit is appropriately scoped and priced;

b. the audit resource requirements are accurately identified;

c. a service agreement is established with the client;

d. audit tasks are allocated to appropriately skilled individuals;

e. a clear work schedule exists for the onsite activities and delivery of the final audit report;

f. the client delivers on its responsibilities under the service agreement;

g. any third-party contracts are facilitated and managed; and

h. the client- and peer reviews (as required) are completed.

Audit Expediting: to ensure the required data is collected according to the audit scope and objectives, in a manner that is consistent with the requirement of this Audit Standard. Expediting includes:

a. liaising with the site operations, maintenance and engineering staff to ensure site procedures are recognised in the logistics of the audit;

b. analysis of the audit data; and

c. drafting and finalising the audit findings and recommendations.

It is expected that these functions will be performed by a person who has the requisite heating systems qualifications, experience, and abilities to undertake the data collection, analyse the data, draw sound conclusions and provide quality recommendations. Such skills would typically be expected of a heating systems auditor certified or accredited by an independent certification body or reputable professional association such as EMANZ or IPENZ.

2.3.3 Communications

An initial meeting between the audit manager and relevant site management should clarify the audit objectives and scope.

A second meeting, including the audit expeditor and site management and operations staff, should be used to:

a. review any preliminary (pre-audit) information that has been collected;

b. assist refinement of the measurements, tools and methods required for the audit to ensure client expectations will be met; and

c. ensure that there is an understanding of what resources are required onsite as well as employee involvement.

2.4 Peer Review

The audit process may include a peer review by a third party also competent in heating systems auditing.

The inclusion of such a peer review would either be a requirement of the agreement between the auditor and the client or at the auditor's discretion for internal quality assurance purposes.

2.5 Audit Costing

Costing of the heating system audit is an important part of the audit planning process.

For an investment-level audit, the cost will depend on the size of the site, the number of heating systems and system boundaries that have been defined in the scope, the level and duration of energy, flow, pressure, temperature and product flow measurements required, and any third-party contractors required to undertake measurements. It may also need to include recognition of post-audit performance monitoring that may be required by the client.

For a base-level audit, the measurement and reporting requirements will be significantly less — with a flow-on effect on the auditing cost estimate.

The quoted cost to the client should also take into consideration any support available from third parties. For instance, there may be services or funding provided by boiler manufacturers, energy retailers, and potential project grants from EECA or other parties.

2.6 Audit Approach in Summary

Figure 2 outlines the general audit approach that should be followed. It commences with client consultation regarding the objectives and scope of the audit (as covered in 2.1 above).

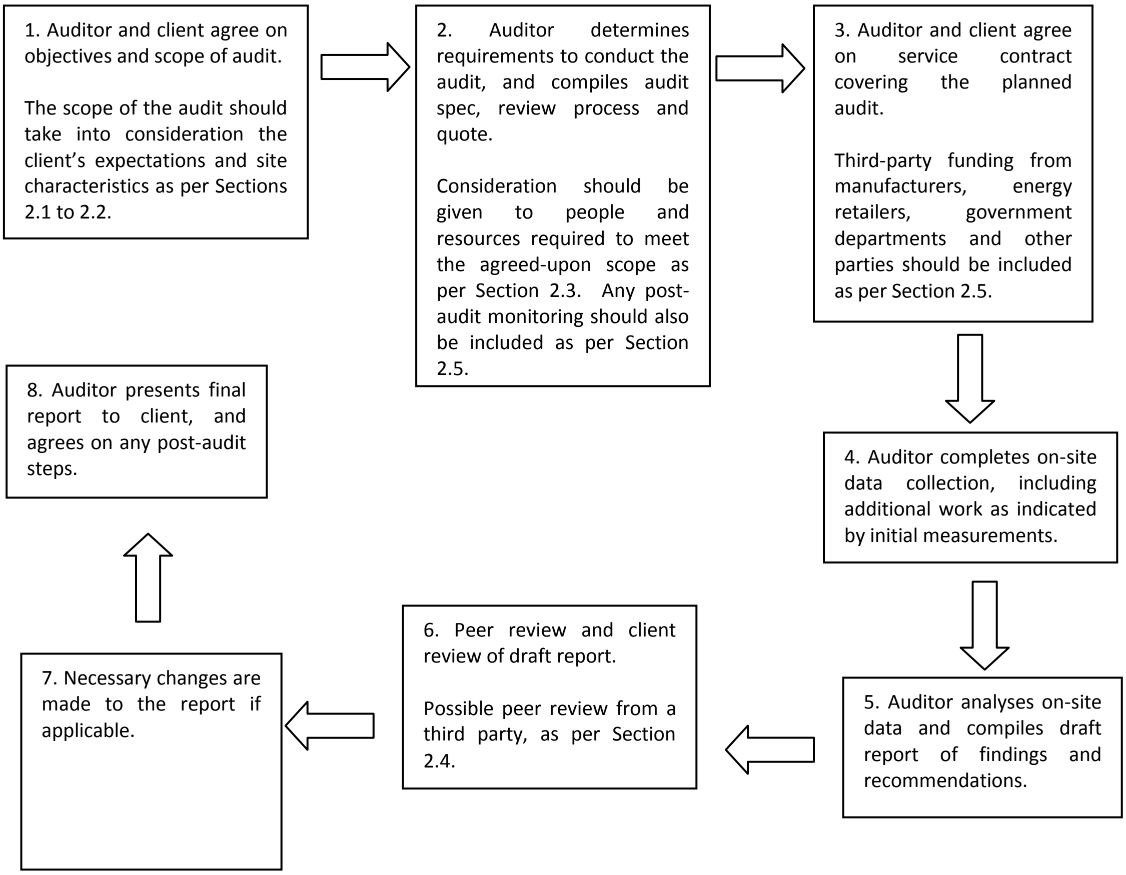

Figure 2: Flow Diagram of Audit Approach

2.7 Post-implementation Monitoring

An audit will generally be followed by implementation of recommended corrective actions.

Pre- and post-implementation monitoring of fuel and electricity usage relative to the heating system requirements or business driver is generally important to the client to enable the value of post-audit design or operations changes to be measured on an ongoing basis.

The nature of the post-implementation monitoring should be established as part of the audit planning, as it is likely to influence some aspects of the audit design and location of temporary or permanent measurement equipment. The key driver of heating system energy input should govern the nature of the monitoring, whether that driver be production output, another input or merely hours of operation.

3.0 On-site Measurements and Data Collection

This section details the measurement requirements for a Process Heat system audit conducted to investment-level accuracy, and provides some guidance on what may be sufficient when auditing to the (lower) base level of accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

3.1 Measurement Methods

3.1.1 Pressure Measurements

Pressure measurement techniques vary depending on the part of the heating system being measured, the pressure ranges and therefore the accuracy of the measurement required. In general, there can be three levels of measurement with various measurement equipment depending on the application:

- Low Pressure (pressure<250Pa) —flow through a duct, furnace/oven or draft through a burner. Suitable measurement equipment includes an inclined manometer or digital manometer.
- Mid-range Pressure (pressure<7kPa) —combustion air and gaseous fuel flow. Suitable measurement equipment includes a liquid manometer or digital manometer.
- High Pressure (pressure>7kPa) —steam, fuel oil and compressed air. The pressure measurement for higher pressures requires the use of accurate calibrated gauges or pressure transducer.

It is important to note that low-quality pressure gauges are easily accessible and at low cost, but often will not provide the accuracy required for later analysis. Liquid-filled manometers are inherently accurate but can be impractical, while digital manometers are also accurate but require regular calibration to maintain their accuracy.

The accuracy of a pressure measurement instrument should be verified by comparison of its measurements with those from a gauge calibrated according to a standard such as AS 1349:1986 or BSI EN837.1.

For a base-level audit, it is recommended that values are noted if there are pressure gauges or transducers already in the network.

3.1.2 Flow Measurements

Knowledge of liquid or gas flows is important to understand a heating system’s performance. Intrusive flow meters may be used, although installation can be difficult or disruptive to production. Non-intrusive ultrasonic flow meters are a useful tool in determining system characteristics, especially in the case of closed-loop hot-water systems.

Flow measurement varies depending on the part of the heating system being measured, whether the flow is gaseous or liquid, as well as the accuracy of the measurement required. Flow can generally be categorised into three main types, with various suitable measurement equipment depending on the application;

- Combustion Air or Gas Flow —several different devices are suitable depending on the application, including an orifice meter, differential manometer/pitot tube, inline turbines and a flow scope.
- Liquid Flow (e.g. water, fuel oil, other process liquids) —suitable devices include external clamp-on ultrasonic flow meters, electromagnetic flow, vortex meters, and inline turbine or roots flow meters.
- Steam Flow —there are various types of steam-flow meters that are often installed during the commissioning of a steam system. A common steam-flow meter is the simple orifice plate meter, although it has limited turndown so may not be suitable if a wide flow range. A Variable Area meter, which has turndown of 100:1 is a good selection for measuring a wide flow range

Ideally, some of this equipment will already be installed onsite, as it may be difficult to install this equipment (especially intrusive meters) in an industrial setting due to production requirements. This highlights the need for advanced audit planning to ensure that all measurement requirements are met. This may require the installation of measurement devices outside regular production periods.

It is important to note that there are many factors that can influence a flow reading obtained from a meter, and the suitability and accuracy of each meter must be understood. Meter accuracy is generally affected by turbulence and so requires a certain length of straight pipe upstream and downstream; installation near valves or elbows, for instance, will negatively affect the accuracy of the readings from the meter. The condition of the heating medium may also affect readings, for example air bubbles in water flow, or condensate in steam flow. Density compensation is usually also required for gas and steam metering to ensure flows are accurate when pressure and temperature vary.

Because flows may be dynamic, periodic and transient, local flow measurements should be taken over a period that captures the full range of operating requirements. Periods of maximum and minimum demands need to be captured, as well as rates of change of flow.

3.1.3 Temperature Measurements

Knowledge of liquid or gas temperatures is crucial to understand a heating system's performance. Temperature measurements vary depending on the part of the heating system being measured, whether the flow is gaseous, liquid or solid, as well as the accuracy of the measurement required. Temperature measurements can be categorized into three groups based on the state of the substance being measured;

- Gas Temperature —several different devices are suitable depending on the temperature. For lower temperatures (<600°C), a thermocouple or resistance thermometer (RTD) is sufficient, while at higher temperatures (>600°C), where radiation is a large factor, suction pyrometers may be required.
- Liquid Temperature —for low-pressure situations a resistance thermometer (RTD) is sufficient, while at higher pressures or in abrasive environments thermometers must be in thermowells (often already installed at various locations throughout a distributed heating system).
- Solid Temperature —if temperatures are low enough and the solid surface is accessible, a thermocouple or resistance temperature detector (RTD) is recommended. However, for higher temperatures and less-accessible surfaces, thermal imaging cameras and/or optical pyrometers are very useful. Thermal imaging cameras are particularly useful for insulation surveys of the piping network of distributed systems. It is important to note that the emissivity of solid surfaces must be known, as this parameter is used by thermal imaging software to determine the temperature of a material's surface. Particular caution must be taken when measuring the temperature of surfaces with low emissivity, such as stainless steel, as this may lead to large measurement errors.

Most heating systems have in-built temperature measurement systems, as this is usually the most important variable that must be controlled within a heating process.

In all cases of temperature measurement, the most accurate measurement will be taken directly from gas or liquid flows or solid surfaces. If this is not possible, the surface temperature of piping or ducts can be used, and in this case RTDs or thermocouples must be covered by a piece of insulation.

Because temperatures often vary for a given process, local temperature measurements should be taken over a period that captures the full range of operating requirements, including periods of maximum and minimum demand.

3.1.4 Energy Usage Measurements

Electricity Usage
For investment-level audits, electricity usage should be measured at the terminals of the heating devices or at the terminals of motors driving auxiliary equipment such as fans and pumps. For each pump motor, a three-phase electricity meter (with data-logging) should be used to record kilowatt (kW) and kilowatt hour (kWh) usage. Particularly where the equipment exhibits variable demand characteristics, it is recommended that the power readings are logged at intervals of not greater than 10 seconds. For instance, electric resistive elements within an oven may switch on and off regularly to maintain changing temperature set points.

If the electricity line charges are based on kilovolt-ampere (kVA) measurement and the site does not have power factor correction upstream of the electrical users, kVA demand should be either directly measured or otherwise assessed.

Fuel Usage
Measuring the fuel consumption of different fuel-burning heating devices may be much more difficult than for electrical devices. A wide variety of fuels exist, including natural gas, different grades of oil and waste oil, biomass such as wood chip and sawdust, and different grades of coal. In some plants, fuel usage of different devices will be measured; however, in many cases this will not occur. For fluid fuels, refer to Section 3.1.2 for flow measurement techniques. To measure solid-fuel usage, direct observation of the consumption should take place if the consumption is not already monitored.

Measurements of electricity and fuel usage should be taken for a period of time sufficient to capture the weekly operational pattern of the heating system. For instance, electrical loggings of a boiler can be useful by showing the cycling of the burner, though temperature loggings will be required to determine if the boiler is in high-fire or low-fire if it is a two-stage system. In addition, in order to put the weekly profile into an annual usage context, it is necessary to obtain an annual profile of production and/or energy use. Investment-level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

For base-level audits, the 'Baseline Consumption Table' provided in Appendix 3 identifies the data required to estimate a heating system's annual electricity use.

3.1.5 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the electricity costs used in valuing the electricity consumption of the heating system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (heating system consumption) patterns. Any seasonal electricity price variations should be recognised in any calculation of production-weighted annual average prices.

The effect of any demand and/or capacity charges should also be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference.

For the purposes of a base-level audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use.

If relevant, the effect of power factor on delivered electricity costs to the heating system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point. The audit should identify if the site would benefit from the installation of power factor correction equipment at the main switchboard (or any sub-board for the supply of heating systems), as that information is important to the assessment of existing and future delivered electricity costs for the site concerned.

The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

3.1.6 Fuel Cost Estimation

As for electricity consumption, wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the costs used in valuing the fuel consumption of the heating system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (heating system consumption) patterns.

Fuel consumption differs from electricity consumption in that combustion efficiency and thermal efficiency must also be taken into account to determine the true fuel cost (or 'effective energy cost'). For example, in the case of a steam boiler system, combustion analysis of the burner may reveal a fuel combustion efficiency of 80% during typical operating conditions and the thermal efficiency of the boiler as 95%. For a fuel cost of $0.04/kWh, the effective energy cost for any user of the steam produced is therefore $0.053/kWh ($0.04/{0.80x0.95}). There are also several other factors to consider when determining the true cost[1] of heat use, especially for complex dynamic systems.

For the purposes of a base-level audit, if the client does not have a standard fuel cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average fuel cost (total cost divided by total energy consumed) for the valuing of fuel use, and typical combustion and thermal efficiencies can be assumed.

3.1.7 Works Cost Estimates

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such will require consultation with a range of equipment suppliers or maintenance engineering companies. The level

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[1] The U.S Department of Energy 'How to Calculate the True Cost of Steam' document provides detailed methods for determining the cost of steam use. Many of the same principles can be applied to other distributed systems.

of accuracy of the cost estimates should meet the client's requirement. For investment proposal purposes, the accuracy expectation will typically be in the order of ±15%.

3.2 Heating System Measurements

3.2.1 Site-level Data Collection

Appendix 1 contains a form outlining the key site-level data that should be recorded for the audit, irrespective of the accuracy level of audit concerned. There are several sources of data that can be utilised such as plant personnel, equipment nameplates, equipment operating manuals, system drawings, and supplier catalogues. It is important to note that documentation is often out of date or redundant due to system changes, in which case onsite staff are usually the most valuable information resource.

3.2.2 Business Requirement of the System

Understanding the requirement that the business has for the heating system being audited is a prerequisite to identifying areas of inefficiency. It is useful to commence the audit with quantification of that requirement, which necessitates collection of the following information:

- the functional (flow, pressure, and temperature) requirements of the system relative to the main business driver (e.g. production); and
- any changes to system design since installation, and the reasons why.

A system schematic is important to provide a clear picture of the interrelationships between the heating system's components and how the requirements may be delivered.

3.2.3 Operating Characteristics

An understanding of the actual (as opposed to the required) operating characteristics requires data collection across the demand, network and supply components of the system, and quantifying the relationship between fuel or electricity use and the relevant business driver of system demand.

Appendix 2 contains forms and diagrams that identify the data required to gain such an understanding and that are potentially useful for an investment-level audit. More detail on the measurements of that data is provided below, with Sections 3.2.5, 3.2.6, and 3.2.7 covering demand, network and supply measurements respectively.

For base-level audits, Appendix 3 provides several forms that identify:

- a minimum level of data needed to estimate a heating system's annual energy consumption (fuel or electricity use); and
- checklists that could be used to assess the key components of the system as they affect system efficiency. Note that there is a separate steam system checklist as well as a general heating system checklist since steam systems have several specific issues.

System run-hour data should be verified by site personnel wherever possible, as the economics of potential efficiency opportunities will depend heavily on that information.

3.2.4 Energy Use and Business Driver Relationship

For investment-level audits, the baseline energy usage measurement obtained from the audit should quantify the Heating System Energy Intensity (HEI), expressed as the heating system's energy consumption per unit of the associated business driver (e.g. kWh natural gas consumption per kg of production output). In addition, the audit should determine (and quantify) any relationship between the HEI and different levels of production activity.

The nature of the monitoring should be governed by the key driver of heating system fuel/electricity input, whether that be another production input, output or merely hours of operation.

For practical purposes (particularly for post-implementation monitoring) the HEI may be established by metering a single or small number of key 'reference meters' rather than attach fuel or electricity meters to all energy consumers within a heating system. In some cases, simply monitoring the fuel consumption of the entire site with respect to production may be the most effective and relevant form of pre- and post-implementation monitoring.

3.2.5 Demand Data-Collection and Measurements

For each system being audited, record characteristics of the heat-transfer medium, how it is being transferred and how it is being used or misused, including:

- nature of the heat-transfer medium, including properties that influence the requirements and performance of the system;

- heat-use isolation practices;
- peak-load shedding practices for electrical equipment;
- identification of inappropriate uses of the heat (and hence questionable demand);
- the nature of product handling and scheduling in the case of batch systems;
- pressure measurements, including the pressure of the heat-transfer medium through major heat users;
- flow measurements, including the flow of the heat-transfer medium through major heat users, and flow through auxiliary equipment such as pumps or fans;
- temperature measurements, including the temperature of products, the inside of furnaces and ovens, or the heat-transfer medium through major heat users;
- heat-transfer medium leakage (e.g. steam leakage), estimating each leak rate where possible;
- temperature measurement of solid surfaces to determine heat losses associated with heat users or the heat containment effectiveness of ovens and furnaces.

3.2.6 Network Data-Collection and Measurements

In the case of indirect heating systems, network measurements must also be considered. Record key characteristics of the network delivering and returning the heat-transfer medium, including:

- pipework or ducting configuration and sizing;
- areas of high pressure/frictional losses including under-sized pipework;
- the level of network maintenance practiced;
- the effects of any valves, meters and filters, particularly any misuses;
- the effects of any alterations made to the heating system network’s original design;
- steam trap conditions;
- pressure measurements, including the pressure losses across major network components;
- flow measurements, including the flow of the heat-transfer medium through major sections of the network;
- temperature measurements, including the temperature of the heat-transfer medium at different points throughout the network;
- temperature measurement of solid surfaces to determine heat losses from pipework or other components. This is useful for later analysis of potential insulation initiatives.

Note that identifying areas of high pressure loss and frictional loss in indirect distributed systems may require additional software assistance. There are several software packages that may aid in identifying potential network inefficiencies.

3.2.7 Generation Data-Collection and Measurements

Record the key characteristics of the generation side of the heating system, including:

- nameplate information of heating device, including model, type, capacity etc.;
- burner information, including kW rating, control and likely efficiency;
- electric element and motor information, including kW rating and control;
- heat generator energy logging for the period specified through the audit scoping;
- heat generator flow or temperature logging for the period specified through the audit scoping (if an electrical logging does not provide sufficient information);
- the level of maintenance which takes place;
- heat-generation control method and extent of use of the control (expected to be observed through power, temperature, or flow logging);
- pressure measurements, the supply pressure of the delivery medium (such as steam pressure);
- flow measurements, including flow of exhaust gas and fuel consumption;
- temperature measurements, including temperature of input and exhaust gases;
- obtain any previous combustion analysis data from prior tests, which are often readily available;
- temperature measurement of the body of the heat generation device to determine heat losses and therefore the heat containment effectiveness;
- flue gas composition with the use of current measurement systems or via combustion gas analyser;
- the performance of existing heat recovery systems such as boiler economisers;
- blowdown control in the case of steam systems;
- heat-generation plant control practices;
- auxiliary system control such as pumps and fans, including Variable Speed Drive (VSD) information. Note that there are other auditing standards for fans and pumps which outline the optimum control methods for such systems.

4.0 Heating Systems Data Analysis

Section 4.0 covers both direct and indirect heating systems. With respect to indirect heating systems, particular focus will be given to steam and hot water systems as together they are the most common forms of indirect systems. Despite this, many of the analysis principles can be applied to all other forms of distributed heating systems with different heat-transfer media such as thermal oil. Likewise, many of the analysis principles discussed with respect to indirect distributed heating systems can also be applied to direct heating systems.

For a base-level heating system audit, observations and measurements are relatively low in detail, and analysis consequently relies on significant assumptions. In many cases, it will be impossible to make any further conclusions about the operation of the system without equipment to take more in-depth measurements.

For an investment-level heating system audit, observations and measurements must be in much higher detail than for a base-level audit. This minimises assumptions that must be made for subsequent analysis. In some cases, it may still be impossible to make further conclusions about the operation of the system if information such as relevant burner information, temperature measurements, electrical loggings, pressure measurements and flow measurements cannot be obtained.

Process heating systems come in a wide variety of forms. Systems can range from direct heating of a product with a flame to complex processes involving highly controlled temperatures such as for annealing. Because process heating systems encompass such a diverse collection of technologies, this audit standard cannot provide in-depth guidance for all systems, but will cover broad principles that should be evaluated when assessing a system[2].

It is important to note that any assessment should focus first on the demand side of a system before any optimisation of the supply side. Often, supply-side measures are investigated without first considering potential measures to reduce the demand, and this is not ideal. For this reason, demand-side analysis is initially covered in Section 4.1. Section 4.2 covers system network (distribution) analysis, Section 4.3 covers system heat generation (supply-side) analysis, and Section 4.4 covers waste heat recovery analysis.

4.1 Demand-Side Assessment

Analysis of heating demand throughout a heating system requires the optimisation of heat use. Solutions to improve the efficiency of this use include, but are not limited to:

- manual or automated isolation of heat users
- scheduling of electrical heating system operation outside electricity network peak charge periods
- reduction of heat or temperature consumption by users
- reduction of pressure requirements by users
- reduction of flow requirements by users
- reduction in leaks, particularly relevant to steam leakage, direct heating and indirect high-temperature fluids such as thermal oil
- improvement of heat-exchange surface
- ensuring all system components are adequately insulated
- utilisation of lash steam within the heating system

Any improvement in the use of heat on the demand side ultimately reduces the energy input required from the system's heating device. Calculations of fuel or power consumption reductions must take into account combustion and thermal efficiency. For base-level audits, reduction in fuel or power consumption can be calculated based on assumed combustion and thermal efficiency.

Potential recommendations should be assessed and evaluated using both technical and economic considerations. Where possible, recommendations should be selected and reported to the client before the supply-side study is undertaken so that feedback from the client with respect to the likelihood of any implementation can be factored into any supply side study.

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[2] Note that this document only provides guidance as to the requirements expected from a process heating system audit and should not be considered a technical document. For more in-depth technical information, refer to specialist text books.

4.1.1 System Considerations

When looking to reduce the heat consumption throughout a system, extra consideration must be given to the devices that may be affected by such reductions. It is important to understand the entire requirements of the heating system before recommending any demand-side reductions or control changes.

In the case of distributed systems, there are many different system sizes, configurations, operating requirements and end uses of the heat-transfer medium. Because of this, there are multiple ways to optimise the whole system. For this reason, focusing on the demand side initially is a suitable option, though a more holistic view of the system must always be made. Each change in demand must be assessed in context with the performance of the whole system and must take into account how each component interacts with another.

4.1.2 Heating Process Improvement

In order for demand reductions to be identified in a systematic way, basic pinch analysis or heat integration should be conducted so that the following items are established:

- performance targets (e.g. minimum energy targets);
- demand reduction opportunities from process modifications and appropriate use of current utilities;
- heat recovery opportunities via heat exchanger network improvements;
- evaluation and comparison of various alternatives.

The demand-side study can be broadly divided into four distinct phases:

1. mass/energy balance preparation and data extraction (Section 4.1.3);
2. benchmarking & targeting (Section 4.1.4);
3. heat exchanger network analysis (Section 4.1.5);
4. evaluation of demand reduction opportunities.

A broad outline of the procedure is shown in Figure 3.

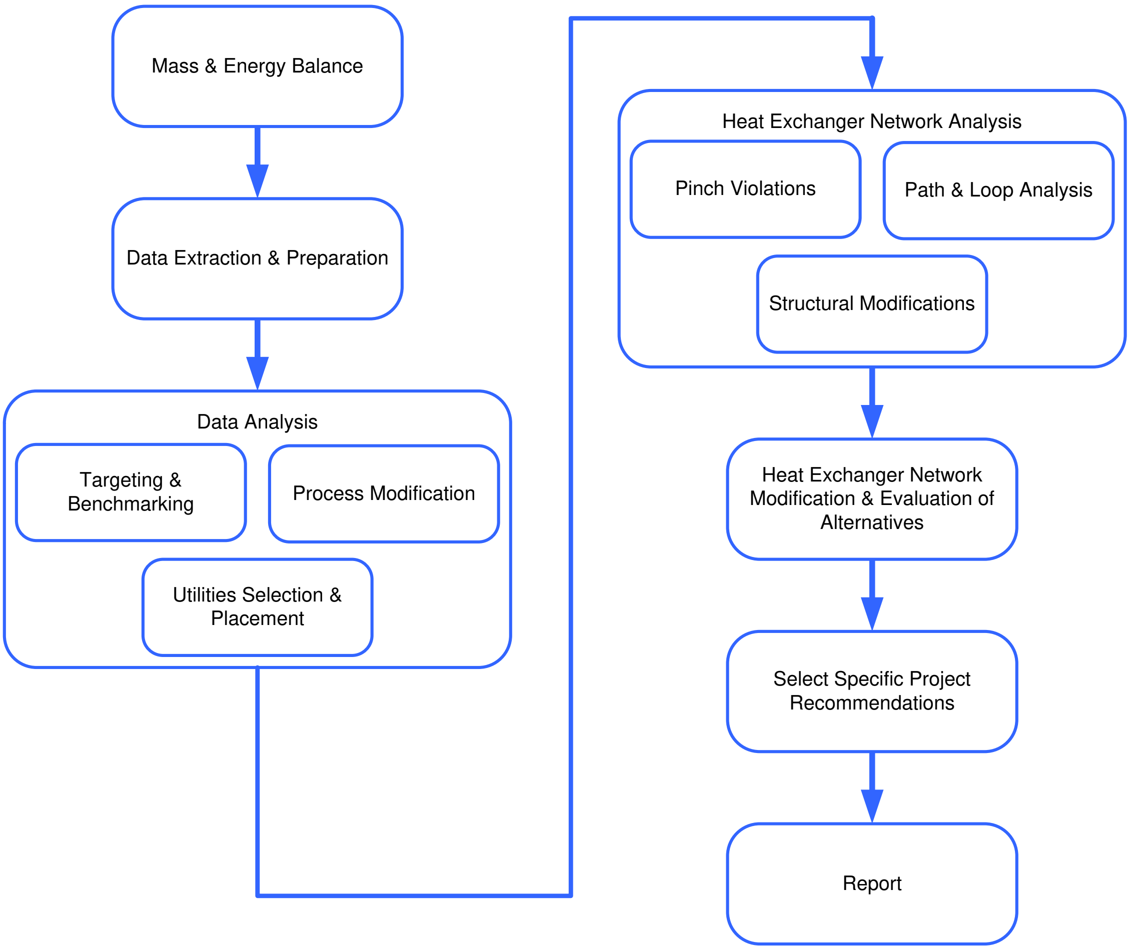


Figure 3: Demand Analysis Procedure

For a distributed system there are multiple process end uses. Much of the opportunity within a distributed heating system is related to the optimisation of this heating process. This means examining the effectiveness of the users in achieving their ultimate business goal. Improving a system's process can be categorised into three broad improvement types;

1. improvement of the current users — in some cases the current heat user is acceptable but not optimised. For instance, open vessels may use hot water to heat their contents, losing much heat to the atmosphere, and this can be improved by installing covers on the vessels.
2. improved user control — in some cases the current heat user is acceptable but is not controlled adequately. Lines that are not in use can often be manually (or automatically) isolated to reduce unnecessary heat loss.
3. replacement of the current users with alternative technologies to achieve the same outcome — in some cases the use of the distributed heating medium may be inappropriate and should be eliminated, such as hot water that is used unnecessarily to clean a workshop floor. In other cases a more efficient technology may be available, such as utilising backpressure turbines to reduce steam pressure for low-pressure applications, instead of throttling valves.

Several important aspects of a direct heating system's process that should be considered (and measurements taken) include:

- recirculation of heated air — fans can be used to ensure that the temperature throughout a heated space is uniform, which may improve product quality and process efficiency
- temperature zoning — this more effectively heats product to different temperatures within different zones. Ensuring that product gets the right amount of heat at each stage of a process minimises overheating and therefore waste energy consumption.
- heating process control — relates to energy loss associated with reheating spaces or product. Especially for batch processes, minimising the inter-batch time period can save significant amounts of energy.
- load scheduling and material handling — relates to a product's time spent in heated spaces and to the scheduling of production. Optimising the time required for a product to be heated will improve process efficiency and therefore energy consumption, while scheduling may involve avoidance of peak charge periods (for electric heating) or taking advantage of external conditions during different periods of the day.
- advanced material use — some parts of a process may require cooling for functionality and longevity of the materials in question, which therefore means reheating must take place. Use of advanced materials can reduce the requirement for cooling and thereby allow heat to be maintained throughout a process.
- use of sensors — having adequate sensors to monitor the heating process ensures that performance is maintained and energy consumption is minimised. Capturing data for historical analysis can also lead to further system improvements, and data trends can be assessed to pre-empt problems.

4.1.3 Mass & Energy Balance

The auditor should compile both a process flow sheet and a mass and energy balance of the current process, including the current heat exchanger network. When the auditor is supplied a mass and/or energy balance or flow sheet from the site, they should verify that it is correct and reflects the actual operation of the plant under typical conditions and not just the design values. In many instances there are significant differences in the design values and actual operational values at many sites due to process changes/modification or to changes in production rates or products. Where there is data missing or the "balance" does not in fact balance, the auditor (with input from informed site personnel) may need to make reasonable assumptions or take additional measurements. Steps may also be required to verify or confirm existing data where that data is critical to the overall balance. Typically a steady-state balance is sufficient, although in some situations an unsteady balance may be required. Potential transient stream properties, such as temperatures and flow rates, may also need to be taken into account during the analysis, especially for economic evaluation of potential heat recovery opportunities.

4.1.4 Benchmarking & Performance Targeting

Benchmarking and performance targeting should occur before an appropriate heat exchanger network upgrade is considered. Benchmarks and targets are used to evaluate possible design modifications to the heat exchanger network for improved heat recovery, better use of utilities, or integration of other equipment (such as heat pumps, evaporators, refrigeration). Based on the process flow sheet and mass and energy balances, the relevant process stream data should then be extracted, along with the relevant heat exchanger information (areas, duties, etc.) ready for the next two stages of data analysis. The auditor should possess the requisite skills and ability to conduct this stage of the analysis or arrange for it to be carried out by someone competent in the analysis.

Depending on the type and objective of the audit, the benchmarking and performance targeting may include examination of the following areas. Areas with an asterisk (*) indicate the minimum expected for a base-level audit.

- heat-recovery targets* (maximum amount of heat recovery possible)
- overall hot and cold utility targets* (minimum hot and cold utility usage)
- individual utility targets* (minimum individual utility usage)

- optimal ΔT_{min} selection (temperature driving force)
- minimum heat-exchange area
- minimum number of heat-exchanger units

Performance targets should be based on either a typical minimum approach temperature (ΔT_{min}) for the type of process or heat exchange that is taking place. Where there are streams with very high or low heat-transfer coefficients relative to the other streams, a minimum approach temperature contribution should be used. It is not anticipated that specialist software will be needed for this performance targeting stage as spreadsheets can easily be developed in-house, although free targeting tools are available on the internet.

4.1.5 Heat Exchanger Network Analysis

The most important stage from an opportunities identification perspective is the analysis of the current heat exchanger network. There are a number of analysis methodologies available to retrofit problems and each are better suited to different process types and situations. The downside is that some are quite complex and cannot be performed well without the use of specialised software. Therefore the standard requires the auditor to use their expertise to determine what method of analysis best suits the requirement from the client and the specific situation. The heat exchanger network analysis performed in a base-level audit may be simply by inspection, although it would be expected that the following are identified:

- Pinch violations;
- Inappropriate use of utilities;
- Poorly integrated process equipment and equipment;
- Heat exchanger network constraints.

For an investment-level audit, more detailed analysis of the heat exchanger network should be performed to identify opportunities, and should involve several alternatives being generated and assessed. As there are complex trade-offs between energy and capital in the heat exchanger network, it is important to examine several options to ensure that all opportunities are correctly identified and assessed. Care should be taken to ensure that suggested modifications will not compromise the process from a safety, control and product quality standpoint. In situations where the targeting stage indicates a large potential for savings, it may be beneficial to involve specialist expertise to be able to realise the maximum economic benefit of the opportunities. Modifications may include but are not limited to:

- Re-sequencing;
- re-piping;
- stream splitting;
- additional heat exchanger area;
- heat transfer enhancement;
- additional heat exchangers;
- addition of localised flash steam pre-heating sections.

In some cases, especially where the site is large or complex, advanced integration analysis such as total site analysis may be beneficial, and the auditor may require independent expertise to assist them in conducting the analysis. This should be identified during a base-level audit and discussed with the client, as the cost of advanced-level analysis may be sustainably greater, involve the collection of much more data for a more comprehensive and accurate mass and energy balance, and require specialist software.

4.1.6 Duration Curve

A duration curve is a useful data analysis tool for assessing system demands over a certain interval. Demand is best assessed by looking at the loads of each process within a system over a sufficient production time period. The curve is created by ranking the historical or measured data from largest to smallest or vice versa, and plotting with respect to time or percentage of time. Typical examples of a load-time curve and corresponding duration curve are shown in Figure 4.

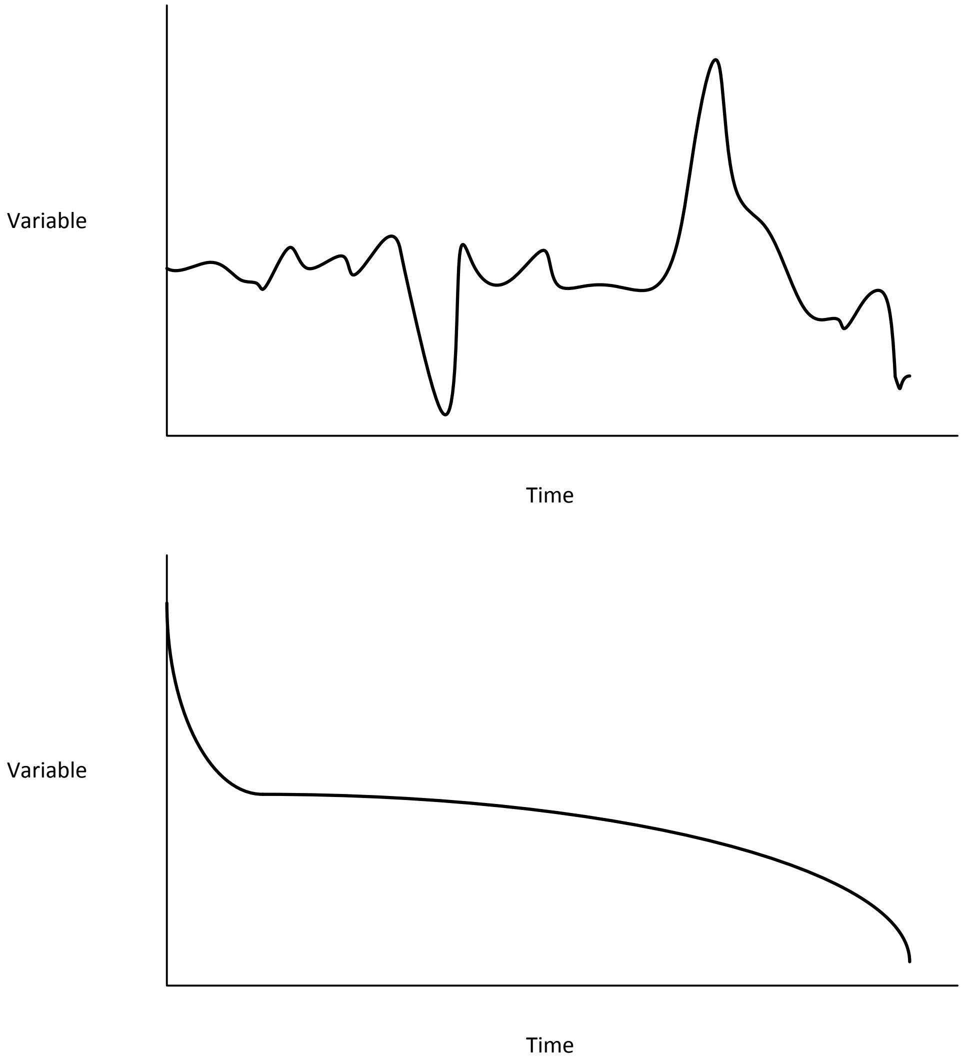


Figure 4: Example of Load-Time Curve (top) with Duration Curve (bottom)

Duration curves may also be able to provide further insight into the sizing of heating devices to meet the site's heating demands. For example, a boiler may be sized to meet large peak demands that only occur for a small proportion of the time. It may be the case that the boiler has poor turn-down efficiency and therefore spends most of the time operating inefficiently. It may then be more suitable to have a smaller boiler supplying the site for the majority of the time so that the over-sized boiler can remain off when not required.

Note that demand curves can be constructed for multiple system users. This will provide a clearer picture of the demand characteristics of the site and therefore assist in determining potential generation-side improvements to meet the demands more effectively.

4.2 Indirect (Distributed) System Network

Analysis of a heating system network requires the determination of the heating fluid's delivery efficiency. This requires the measurement of pressure losses and flow through different sections of the network.

Solutions to improve the efficiency of heat distribution fluid delivery include:

- reducing pressure drops across incorrectly installed valves
- reducing system pressure drops as a result of excessive frictional losses (often caused by undersized pipework)
- the optimising of pipe configuration
- improved network maintenance
- maintenance of steam traps, incorporating a regular testing programme or continuous monitoring, with follow up repair or replacement (for steam systems)
- optimise system air removal (particularly in the case of steam systems)

- optimise system separator operation

It is very difficult to determine the effectiveness of fluid delivery without accurate measurements of flow and pressure, let alone calculate potential energy savings.

If it is noted that network maintenance practices are poor, it is suggested that a percentage improvement in system energy efficiency can be expected as a result of improved practices.

4.2.1 Network Design

It is recommended that software specific to pipe network design is used to analyse the system's delivery effectiveness. Modelling the system using software will quickly identify areas with excessive frictional losses as a result of undersized pipework, and areas with pressure losses as a result of incorrectly installed valves or pipe configuration.

4.2.2 Steam Trap Testing (for steam systems only)

Steam trap testing is highlighted separately since it is often the cause of significant steam system heat loss. It is common in steam systems that have not been maintained for several years for 15% to 50% of the installed steam traps to have failed.

Most of the energy stored in steam is in the form of latent heat. Failure to recover that latent heat, due to a faulty steam trap, results in major energy loss and often represents an opportunity for significant cost savings. To avoid large energy losses, a steam trap management programme should be put in place that:

- trains site staff or use the services of a specialist provider
- inspects every steam trap on a regular basis, with particular emphasis on critical equipment. Trap testing must be done while the plant is running, and repair can often coincide with other remedial work. Alternatively, equipment for continuous steam trap monitoring may also be used, particularly on critical plant or where potential losses are high.
- assesses its operating condition
- maintains a database of all steam traps, both operational and faulty
- identifies the suitability of traps and ancillaries
- determines the cost of energy loss from failed traps
- acts on the assessment findings.

Again, it can be difficult to assess the energy loss from faulty steam traps. Losses from steam traps can be estimated based on the condition of each trap tested, and the calculated steam flow that may result if it has failed, as determined from trap orifice size and steam pressure.

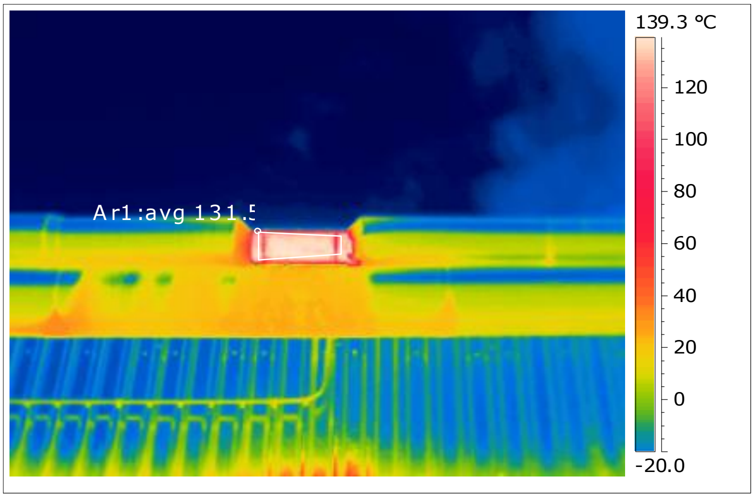
Also, for closed systems, it can be assumed that most of the steam leaks are due to faulty steam traps, and taking into account direct steam uses, the boiler's blowdown and condensate return rates, most of the remaining make-up water amount can be associated with faulty steam traps. The potential energy saving achieved by repairing steam traps is therefore the difference in energy content between make-up water and returned water.

4.2.3 Insulation Opportunities and Heat Containment

Maintaining insulation in good condition is vital to an energy-efficient heating system, especially for a distributed system. Without effective insulation on all supply or return piping, valves, flanges and other equipment, heat loss (and therefore heat waste) can be significant. Removable jackets are an effective solution where sections must be accessed, such as exposed valves.

Thermal imaging is a common method for finding exposed or damaged insulation, although there are other viable alternatives. It provides a relatively sound method for estimating the heat loss from each section, although caution must be taken to ensure that surface emissivity is accurately assessed, since this greatly affects measured temperatures. An example of a thermal image is shown below, with the estimated potential energy reductions that can be achieved via insulation shown in the adjacent table.

Image Time	8:35:41 AM
Date	8/10/2011
Ambient Temperature (°C)	21
Surface Area (m^2)	0.52
Annual Run Hours	8,760



Emissivity	0.70
Heat Loss (kW)	0.86
Insulation Energy Reductions (kWh)	6,027
Energy Cost Reductions ($)	548

Other alternative methods to determine heat loss from sections include:

- direct temperature measurement of each surface; or
- indirectly determining heat loss by measuring change in energy content of the thermal fluid within a distributed system or by comparing heat input with heat absorbed by the product for a direct heating system.

Radiation and convection theory used to determine the heat loss from a section is described in Appendix 5. For effective insulation of a surface, a conservative assumption of 80% reduction in heat loss can be assumed.

Insulation is also a concern for direct heating, as the heat-containment effectiveness of direct heating devices has a large impact on the energy consumption of that device. It is important to minimise conductive losses to other parts of the system. Connected structures that carry the product to and from the heating space, for instance, can conduct heat away from the heating space. There may be potential to insulate these fixtures near to the heated space, to introduce a thermal break, or to recover heat from the existing product and use this to preheat incoming product.

Another important cause for heat loss is air infiltration or loss. For instance, furnaces are often at slightly negative pressure to prevent the loss of furnace gases to the surroundings, which can result in unwanted air infiltration. Air infiltration can account for a significant energy loss since the air carries heat away from the system via the exhaust. Fixing leaks around the furnace chamber and proper operation of a pressure-control system can be cost-effective methods for improving heat containment.

4.2.4 Fluid Leaks

This refers to any fluid leakage from an indirect heating system, including hot water or steam leaks, and is mostly inapplicable for direct heating systems. Any leaks in the system result in lost fluid and the energy content associated with it, and effort must be made to quantify these losses. It is important to find and repair any leaks as soon as possible.

In the case of steam leaks, they can be a large component of a system's energy losses. Leaks generally occur in pipe sections or connections, stem gland seals and steam traps that drain condensate. Larger leaks can be detected visually and audibly, while ultrasonic leak detection can be used for smaller leaks. It may be possible to eliminate potential leak points, for example by using bellows sealed valves to prevent loss from valve stems.

4.3 Heat Generation

Analysis of a heating system's generation side requires the optimisation of burner and boiler or heating plant suitability, combustion efficiency and system control. Again, this may be difficult to determine without accurate measurements, although assumptions can be made to estimate potential energy savings. Solutions to improve the heat generation efficiency include:

- replacing a heating system with one more optimally sized for the demand
- improve burner/boiler maintenance
- improve burner combustion efficiency via excess air control or oxygen enrichment
- improve flame patterns for more effective heating
- ensure electrical elements are in good condition
- improve generation plant control, in particular capacity control and standby control

- improve auxiliary system operation control, ideally automating when these systems switch on or off, or vary in supply depending on wider system variables such as temperature
- optimise the boiler's water treatment plan and control systems and therefore minimise blowdown frequency
- change to a cheaper fuel source
- ensure the boiler, kiln or oven body is well insulated

Analysis of the heat-generation side requires the optimisation of several facets of the heating system, each interrelated to the other. As for demand-side analysis, it is important to keep in mind the effects that each improvement may have on other parts of the system, ensuring a holistic approach is maintained.

4.3.1 Heat Generation Plant Maintenance

It is best practice to perform regular maintenance on heat generation plant, and particularly important for indirect systems to ensure that the heating plant's thermal efficiency is maintained. The following steps can be used to determine a boiler's efficiency:

1. measure its current efficiency based on measurements of the heating medium's input and output temperatures, pressure, flow rate and burner fuel consumption rate (or electrical consumption in the case of an electric heater)
2. compare these measurements to historical data. For some systems, useful parameters such as this are often recorded in a SCADA system
3. compare the measured efficiency to the boiler's specifications
4. investigate any discrepancy between the boiler's current performance and historical or specified performance

There are several reasons for poor heating plant performance such as faulty body insulation, refractory damage, or scale build-up on the boiler's heat-transfer tubes, limiting heat transfer to the fluid. Increasing flue gas temperature may be an indirect indicator of scale formation.

4.3.2 Heating Plant Suitability

While heating plant, such as a boiler, may be operating relatively efficiently when compared to its design performance, there may be a more efficient form of heat generation or a boiler that is better suited to the system's application. A boiler may be maintained poorly or of such an age that its replacement is more economical than improving its performance via other initiatives. Replacing the boiler may appear to be a large cost, but the potential savings in energy and maintenance costs could make it worthwhile.

To assess whether an alternative heat generation method or new boiler may be suitable, a review should consider several aspects of the system;

- the site's heating requirements;
- the demand profile (as described in Section 4.1.6);
- which fuel supply will be used — biomass, gas, etc.;
- where a new boiler(s) could be located in relation to its heat users;
- the configuration used with a new boiler or multiple boilers;
- potential for a number of smaller boilers located close to the major end-users;
- the opportunity for cogeneration;
- compatibility of the current site heating system;
- how maintenance costs would compare to the original boiler(s);
- potential for a new system to operate more efficiently or with a lower environmental footprint than the original boiler(s);
- potential to eliminate the boiler(s) completely and use heat recovery from other processes on site.

Replacing the heating plant is not as simple as reading the specifications on the nameplate of the old heating plant and ordering a new one with identical specifications. To ensure a review is thorough and accurate, a heating plant technician or specialist engineer may also need to be consulted.

4.3.3 Combustion Efficiency

Combustion efficiency is one of the most important aspects of a heating system, since it ultimately determines how much fuel is used and therefore most of the cost of operating the heating system. It is one of the main areas an auditor should assess.

Most large heater/burner systems will have regular combustion testing undertaken to ensure that combustion efficiency is adequate. Auditors should obtain such reports and assess the efficiency of the system. If testing does not take place or has not taken place recently, the flue gas must be assessed to determine combustion efficiency. Gas-absorbing test kits or more-expensive computer-based analysers can be used in this instance. Some boilers may also have systems in place that monitor some of these parameters already. Analysing flue gas involves measuring the levels of oxygen and carbon monoxide to give an indication of combustion efficiency, and comparing this against performance guidelines. Typically the flue gas oxygen level should be between 2% and 4% for liquid and gas fuels, while for solid fuel combustors the flue gas oxygen level should be between 5% and 7%. Figure 5 shows the generic shape of the percent available heat (which determines combustion efficiency) for a gaseous fuel as the percent excess oxygen is varied and the exhaust gas temperature increases.

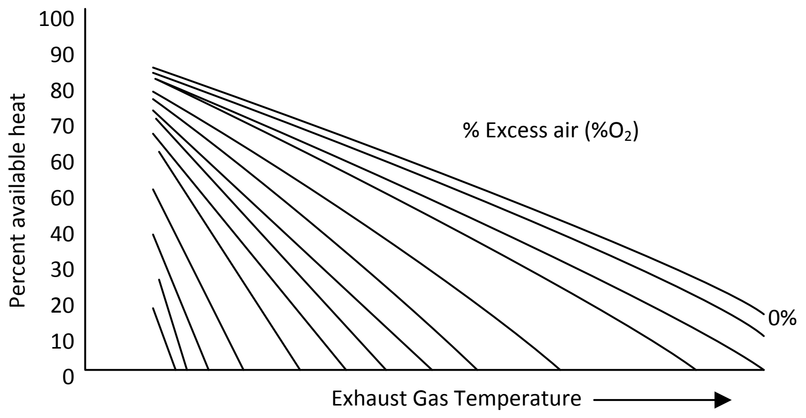


Figure 5: Combustion Efficiency with Exhaust Gas Temperature and Excess Air %

It can be seen that minimising excess air and reducing the exhaust gas temperature reduces the amount of heat lost, allowing more of the fuel energy to be transferred to the heat-transfer medium.

If there is little control in the current system, automated oxygen trim systems may be beneficial, although this may increase maintenance costs because sensors require regular tuning. An automated system is especially applicable for larger systems where fuel composition or demand is variable. An oxygen trim system provides feedback to the burner controls to automatically minimise excess combustion air and therefore optimise the air-to-fuel ratio, bringing the composition closer to stoichiometric.

As well as ensuring that excess air is kept to a minimum, there are other combustion efficiency considerations that are more applicable to direct heating situations:

- assess the condition of electrical inductance heating coils — inadequate condition may lead to overheating of the coil and further deterioration, or less-effective magnetic flux patterns through the space or object being heated
- optimise the frequency setting of inductance coils — relates to heat penetration and potential heat waste
- assess the condition of electrical resistive heating surfaces — hot spots or cold spots may add variability and therefore inefficiencies to product heating
- assess flame patterns — hot spots or cold spots may add variability and inefficiencies
- assess oxygen enrichment potential — may be a practical means to improve productivity by improving combustion, particularly in the primary metals industry

4.3.4 Generation Plant Control

Control of combustion efficiency is not the only concern with regard to control of heating systems. Especially for multiple heating plant systems, the control of other system parameters also plays a large part in determining the overall efficiency of the heating system.

Other forms of control that should be investigated or assessed include:

- multiple heating plant control — ensure the correct plant operates during the optimum system conditions, i.e. ensure heating plant operation matches system demand
- flue draft control — automatic valves that shut when boilers are in standby to mitigate flue draft and heat loss
- heating plant interlock — ensures heating plant does not operate when heating is not required (avoid ‘dry cycling’)
- auxiliary system interlock — ensures auxiliary systems remain off when the heating plant does not require them

- temperature control — optimise the temperature setpoints so that heating plant does not cycle excessively, with a sufficiently large span between the temperature at which the heating plant will restart combustion and the temperature at which it stops combusting

4.3.5 Blowdown Optimisation (for steam systems only)

Blowdown systems, while not applicable for hot water generation or direct heating systems, are a major component of a steam heating system. A significant amount of energy is lost during blowdown cycles, since water is dumped along with the internal energy it contains (unless there is blowdown heat recovery). It is important to optimise the water treatment system so that blowdown is minimised. If solids are not purged from the boiler they can lead to scale formation, embrittlement and corrosion, which all affect heat transfer and can damage system components.

The operation of the current blowdown system must be assessed. Some systems have manual blowdown control, while most systems have automated control. Automated systems monitor total dissolved solids (TDS) in the water to ensure the TDS levels remain within the boiler's tolerance and minimise blowdown events.

Another aspect that must be investigated is the internal and external treatment plans. This relates to the selection of chemicals and processes which together have the effect of maintaining heat-exchanger surfaces within the boiler and throughout the system, minimising heat loss. Reverse-osmosis systems help pre-treat the water before it enters the boiler.

While it is difficult to determine the potential savings achieved by reducing scale formation and therefore maintaining heat-transfer surfaces, the savings achieved by reducing blowdown are easier to estimate. The energy saved is simply the difference between the internal energy of top-up water and blowdown water after boiler combustion and thermal efficiency is taken into account.

4.3.6 Fuel Change Opportunity

There are several different types of fuel that can be used for heat generation, each of which has different advantages and disadvantages. Refer to Appendix 5 for descriptions of the major different types of fuel.

Selection of the most suitable fuel for a boiler application is an important yet often difficult choice. Some options may include natural gas, fuel oil, biomass, and coal. Waste heat from other parts of the plant should also be considered as a 'fuel', as could potential cogeneration systems. Any decision on fuel type should include the following considerations:

- heat plant type and system required
- relative cost of the fuel and stability of these costs (note effects of carbon costs and scarcity)
- fuel storage capacity
- fuel ease of handling
- current/future government or company policies relating to the fuel
- continuous availability of fuel
- the potential for fouling
- maintenance effects
- net environmental impact.

It is important to note that switching to a cheaper fuel may reduce the efficiency of the system, since it may have a lower calorific value and/or higher moisture content, and is often dirtier. Cheaper fuels also often result in higher carbon emissions, and if this is of particular concern then consider converting to biomass, biofuel or other low-carbon fuels.

4.3.7 Auxiliary Equipment Operation

There are several auxiliary systems associated with distributed heating systems, in particular circulation pumps, process fans and pneumatic devices, which should also be assessed. Note that compressed air, fan and pump systems have separate audit standards[3] covering the assessment requirements. While it is not technically within the scope of these audit standards, auxiliary systems often have large potential for energy savings initiatives and are therefore worth considering.

Efficiency of auxiliary equipment drive motors should be considered. In most cases, a motor will be sized to operate within 60% – 100% of its rated capacity, as well as allowing for the starting torque requirements of the device being driven. Motors are correctly sized for their application in most cases, since equipment such as pumps are often supplied as a pump/motor package, although there will be instances where motors are oversized.

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[3] The relevant Pump System Audit Standard, Fan System Audit Standard and Compressed Air System Audit Standards can be found at http://www.eecabusiness.govt.nz/services-and-funding/industrial/energy-audit-grants

The efficiency of auxiliary equipment motors is regulated through Minimum Energy Performance Standards (MEPS), for new motor installations. AS/NZS 1359.5:2004 contains efficiency requirements for three-phase motors rated between 0.73kW and 185kW. The type of equipment-motor coupling should also be considered. The most efficient drive method is direct mechanical coupling, although space, layout and motor speed requirements (the use of pulleys) will not always allow this.

One large opportunity relating to the operation of auxiliary equipment, in particular for pumps and fans, is the potential for VSD flow control. Investigation of options for using VSDs on electric motor drives should be undertaken, particularly where pumps or fans supply variable demands (such as circulating pumps or induced- or forced-draught fans). Speed control is a much more efficient form of control than throttling or damper control, which are both often used in heating systems. As mentioned, this assessment is described further in other audit standards. Note that for direct heating systems, fan control is likely to be the most significant opportunity for auxiliary system improvements.

Poorly tuned control loops usually result in continual or excessive actuation of pneumatic and electric control valves. Improved tuning may reduce the actuation of, and hence energy used, by these control valves. Another area often overlooked is the air consumption of pneumatic control valve positioners. Traditional positioners use a flapper nozzle with continuous air flow, while the latest electronic controlled positioners use considerably less air, with virtually no air used at steady state.

4.4 Heat Recovery

Analysis of a heating system's heat recovery opportunities involves determination of the current heat loss associated with a process, the heat generation system, or other utilities. Heat recovered within the process itself is discussed in Section 4.1.2. This requires the measurement of temperature and flow through different sections of the system.

Potential heat recovery options include:

- condensate return (steam systems only)
- flash steam heat recovery (steam systems only)
- blowdown heat recovery (steam systems only)
- boiler economiser for in-feed pre-heating
- waste heat recovery (e.g. air compressors or refrigeration compressors)
- heat storage, i.e. batch processes that by nature expend heat energy during a cycle may be modified so that some heat is externally stored for re-use by another batch
- waste heat use for absorption cooling or for low-grade plant or product heating

Heat recovered from any part of the system can be used within another part of the process (demand side), such as product in-feed preheating, or can be used within the generation system (supply side), such as for combustion air preheating. Pinch analysis is a useful method for determining heat recovery opportunities and optimising current systems, as described in Section 4.1.2.

Current site heat recovery systems should also be assessed to determine their effectiveness, then in some cases further improved.

For base-level assessments it may be difficult to determine the heat available for recovery without accurate measurements of flow, temperature and pressure, let alone calculate potential energy savings. Consequently, large assumptions are often required, as well as auditing experience.

4.4.1 Heat Generation Heat Recovery

Heat generation heat recovery refers to heat recovery from the heating system itself. There are several heat recovery opportunities for both direct and indirect systems. These opportunities should be analysed to determine the potential system-wide efficiency improvement and therefore energy savings. Some of these opportunities include, but are not limited to:

- Blowdown heat recovery — can be achieved by using this water to preheat feedwater via a fouling-resistant heat exchanger or by flash-steam heat recovery. Assessing the amount of heat-recovery potential involves quantifying the volume of blowdown that takes place. It is important to note that the blowdown system should be optimised first before estimating potential heat recovery.
- Economiser heat recovery — an economiser is a heat exchanger in a burner's exhaust that can be used to preheat low-temperature materials. A common application is to preheat boiler feedwater. Assessing the amount of heat-recovery potential involves measuring exhaust gas flow and temperature. It is important to note that the combustion efficiency should be optimised first before estimating potential heat recovery, as improving combustion efficiency reduces stack temperatures.
- Return heat recovery — most heating systems have return systems (e.g. condensate return for steam systems) since there is such a large amount of energy contained in the return. Assessing the amount of heat-recovery potential of an open system that does not have return heat recovery involves measuring discharge volumes and temperatures.
- Flash-steam heat recovery — low-pressure steam is flashed from high-pressure condensate. This is particularly viable when it is not economically feasible to return high-pressure condensate to the boiler. A flash-steam recovery vessel allows the low-pressure steam to be separated from the condensate, as shown in Figure 6.

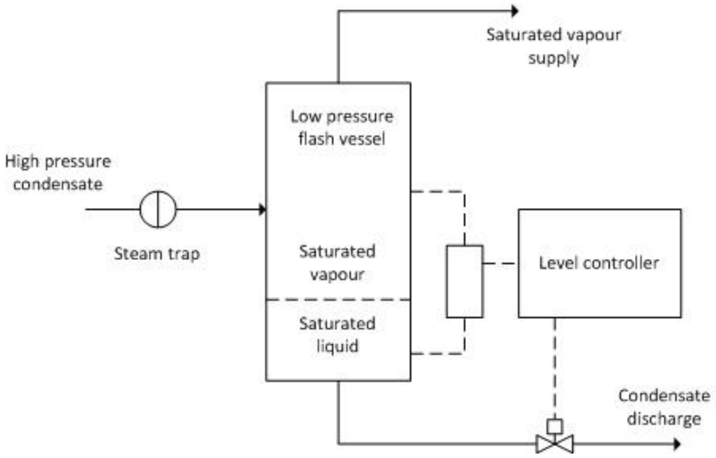

Figure 6: Flash-steam Recovery Vessel

4.4.2 Waste Heat Recovery

Waste heat recovery refers to heat recovery from other utilities onsite. There are several waste heat recovery opportunities for both direct and indirect systems. These opportunities should be analysed to determine the potential system-wide efficiency improvement and therefore energy savings. Some of the sources of waste heat include:

- air conditioning exhaust air
- refrigeration[4] compressors
- air compressors

This waste heat can be recovered in several ways, such as:

- boiler feedwater pre-heating
- combustion air preheating — can often just be a simple redirecting of HVAC exhaust air towards a burner inlet
- process heating e.g. product preheating
- use of thermal storage
- direct heating of heat-transfer medium such as hot water or steam
- cascading — multiple processes with successively lower heating requirements can use the heat waste from the process at a higher temperature.

4.4.3 Absorption Cooling

Absorption cooling is mentioned here separately as it is a unique heat recovery opportunity and requires expertise in refrigeration technology as well as heating technology. Absorption cooling typically involves using low-grade waste heat to power absorption coolers, instead of mechanical energy as is the case for electrical chillers.

Assessing the opportunity for absorption cooling requires comparison between the cost of the fuel that generates the heat (after taking into account combustion and thermal efficiency) and the cost of electricity which is traditionally used by refrigeration compressors. The COP of the absorption chiller will be lower than the COP of typical electric refrigeration systems, requiring heating fuel (or waste heat) to have little or no cost for any absorption cooling system to be economical. Absorption refrigeration design is a specialist skill and expert technical advice should be sought when considering this option.

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[4] With respect to refrigeration systems, separate audit standards exist. The relevant Refrigeration System Audit Standard can be found at http://www.eecabusiness.govt.nz/services-and-funding/industrial/energy-audit-grants

5.0 Whole-system Considerations

Each part of the Process Heat system analysis may include findings that can have some relation to another part of the system.

Consequently, the analysis needs to identify ‘dependent’ and ‘mutually exclusive’ opportunities across the whole system, to ensure that the most cohesive and well-specified recommendation set is made to the client.

Where two opportunities are dependent (one must be implemented in order for the other one to be possible), they may be presented as one saving with one total associated cost. For example, if an oven typically consumes 10kW of fuel and reductions of 30% of the demand for heating and 20% burner efficiency improvements can be made, they should be applied as follows:

Power use after demand reduction = 10kW x 0.7
= 7kW

Power use after burner improvement = 7kW x 0.8
= 5.6kW (or 56% of the original consumption)

If the savings had both been applied to the original 10kW, total savings of 5kW or 50% would have been calculated, overestimating savings by 6% of the original energy use.

Appendix 1 — Site Information Form

Business Name	
Site physical address (Street, Suburb, City)	
Nature of site / business operation	

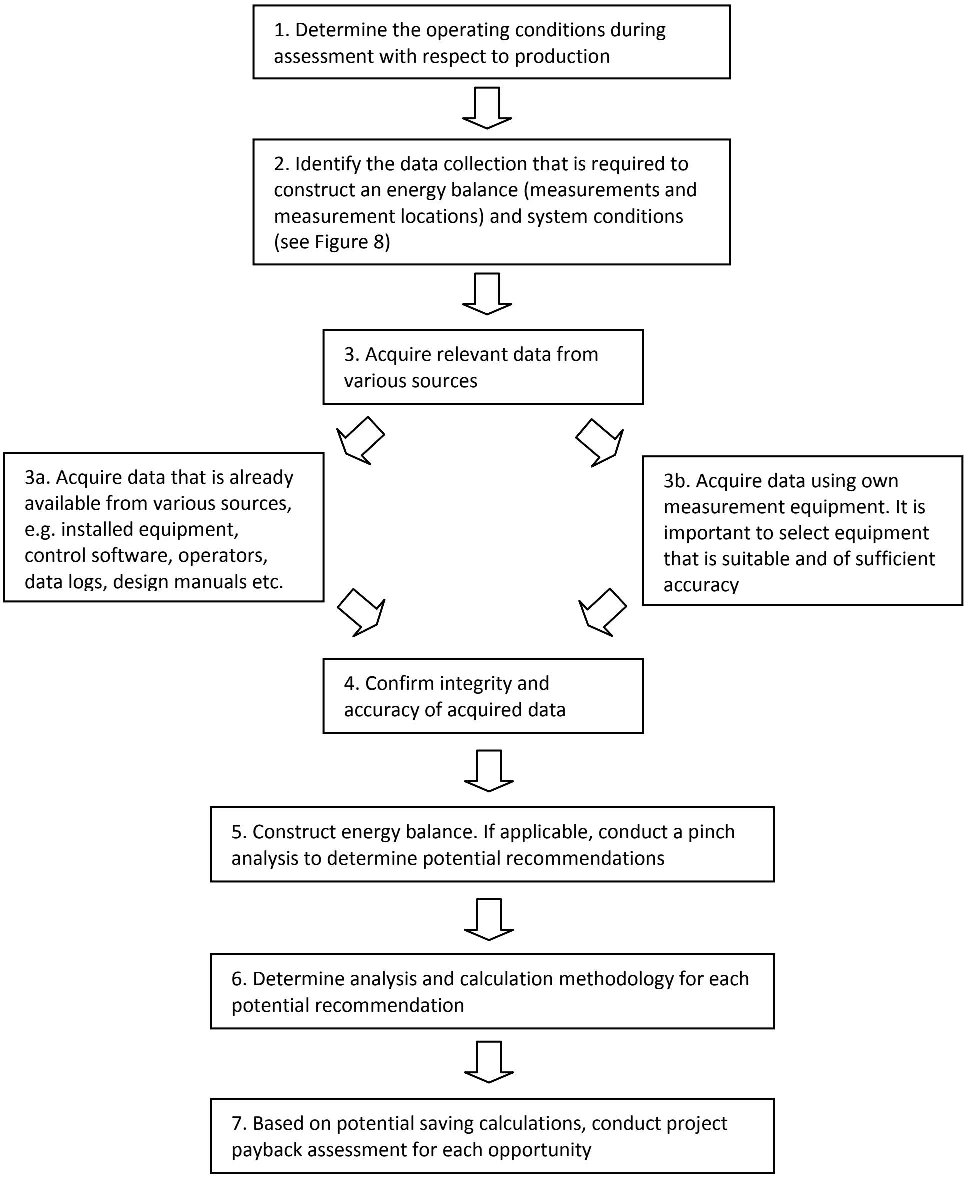
First day of onsite loggings	
Final day of onsite loggings	
Production during period of loggings	
Electricity Supplier	
Other Fuel Supplier(s)	
Power factor correction equipment in use	
Delivered electricity cost per kWh	

Site contact 1:	**Name**	
	Designation	
	Telephone (DDI)	
	Email	
Site contact 2:	**Name**	
	Telephone (DDI)	
	Email	

Comments:

Appendix 2 — System Data Collection

Assessment Activities



1. Determine the operating conditions during assessment with respect to production

2. Identify the data collection that is required to construct an energy balance (measurements and measurement locations) and system conditions (see Figure 8)

3. Acquire relevant data from various sources

3a. Acquire data that is already available from various sources, e.g. installed equipment, control software, operators, data logs, design manuals etc.

3b. Acquire data using own measurement equipment. It is important to select equipment that is suitable and of sufficient accuracy

4. Confirm integrity and accuracy of acquired data

5. Construct energy balance. If applicable, conduct a pinch analysis to determine potential recommendations

6. Determine analysis and calculation methodology for each potential recommendation

7. Based on potential saving calculations, conduct project payback assessment for each opportunity

Figure 7: Flow Diagram of Suggested Assessment Activities

Heating System Data Acquisition or Direct Measurement Suggestions

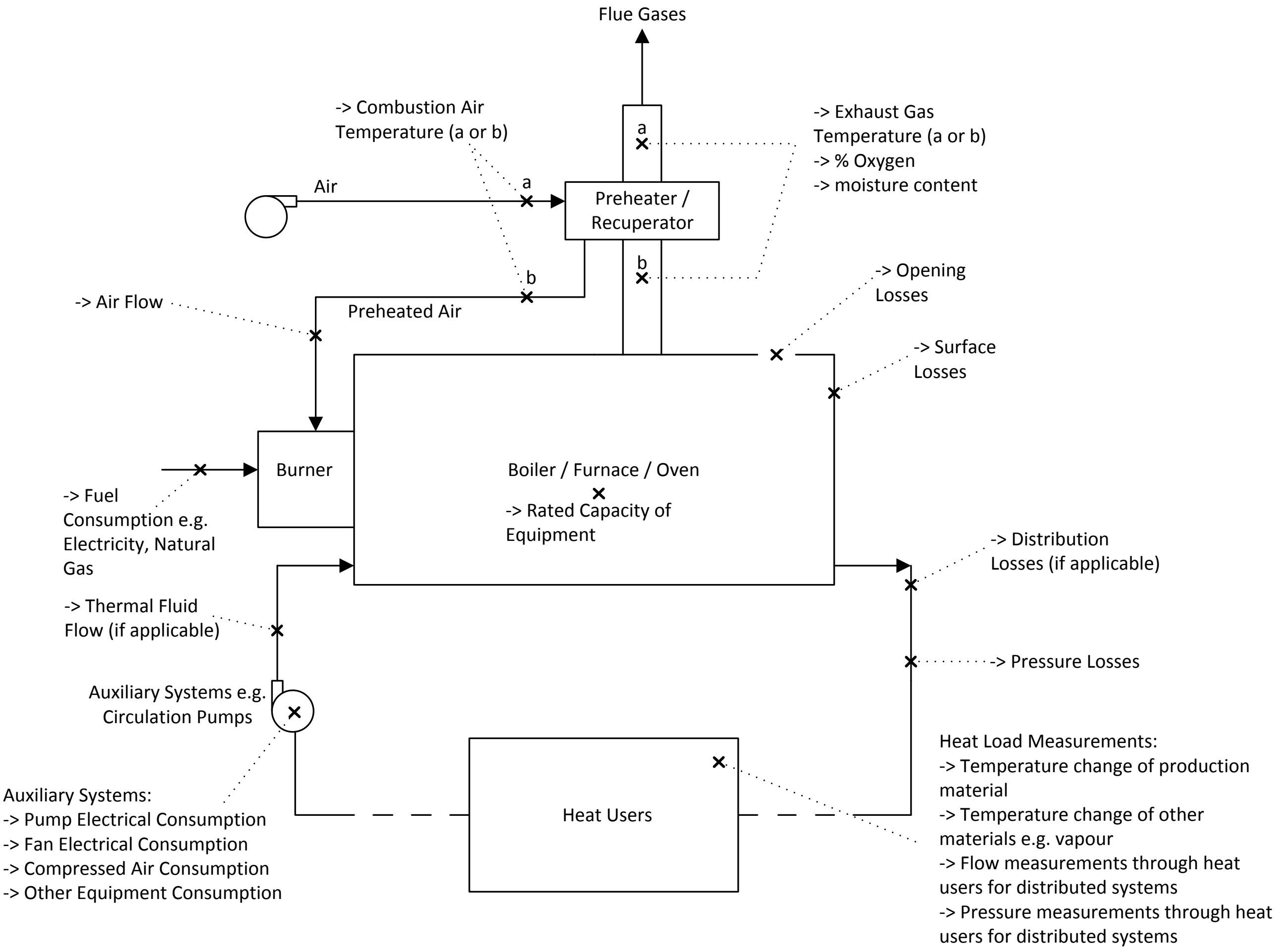


Figure 8: Suggested Heating System Measurements[5]

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[5] The measurements shown in the diagram are not exhaustive and will vary from system to system.

Example Data Collection Form

Network Schematic			
System Reference			
note: include all relevant system components such as burners, boilers, pumps, fans, heat users, heat exchangers, direct injection systems, heat recovery systems and valves			
Heat Generation Information			
Heat-generation Type		Heat Generator Condition	
Fuel Type		Burner Condition	
Heat-transfer Medium		System Pressure/Temperature	
System Operation		Feedwater Treatment (Steam)	
Auxiliary Equipment/Operation		Blowdown Operation (Steam)	
Heat Recovery Information			
Current Heat Recovery Technology Utilised		Effectiveness of Heat Recovery Units	
Potential Heat Recovery Opportunities			
Network Information (if applicable)			
Supply Pipework		***Condensate Pipework***	
Material / Size		Material / Size	
Insulation Condition		Insulation Condition	
Other Information		Other Information	
Valves / Outlets			
Valve / Outlet Types		General Condition	
Insulation Condition		Operation	
Demand Information			
Heat User Name	Description / Comments / General Condition		Pressure / Temperature Requirements

Appendix 3 — Base-level Audit Data Collection and Checklist

One per heating system

Baseline Consumption Table					
Heating System		**Description**			
Thermal Energy Use Details					
Fuel Type		Fuel Cost			
Equipment ID	***Make / Model***	***Rated kW (thermal)***	***Load Factor***	***Annual Run Hours***	***Annual Energy Consumption***
Total Thermal Energy Use					
Annual Thermal Energy Operational Cost					
Electricity Energy Use Details					
Electricity Cost					
User ID	***Make / Model***	***Rated kW (electrical)***	***Load Factor***	***Annual Run Hours***	***Annual Energy Consumption***
Total Electrical Energy Use					
Annual Electrical Energy Operational Cost					
Total System Energy Use Data					
Total Heating System Energy Use					
Total Heating System Energy Cost					
Relevant Production Measure (e.g. units produced)					
Estimated Annual Production Throughput					
Estimated Heating System Energy Intensity (HEI)					

Steam System Checklist

	Assessment Checklist	**Potential for Efficiency Improvement**				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Steam user isolation					
	Appropriate use of steam					
	Steam user insulation					
	Pressure / temperature requirements					
	Steam use / process efficiency					
	Steam leaks					
	Heat exchange surface condition					
NETWORK	Pipe design					
	Network condition					
	Supply pipe insulation					
	Condensate pipe insulation					
	Fitting / valve removable insulation					
	Steam trap testing / maintenance					
	System air removal					
GENERATION	Boiler condition					
	Burner condition					
	Combustion testing and control					
	Supply-side insulation					
	Standby losses					
	Blowdown optimisation					
	Internal water treatment					
	External water treatment					
	Plant operation					
	Steam supply pressure					
	Fuel quality					
	Oxygen enrichment					
	Fuel change					
	Auxiliary equipment operation					
HEAT RECOVERY	Condensate return					
	Flash steam					
	Process					
	Blowdown					
	Economiser (feedwater)					
	Combustion air preheating					
	Absorption cooling potential					
	Thermocompressor potential					

Other Heating System Checklist

	Assessment Checklist	Potential for Efficiency Improvement				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Heat user isolation					
	Appropriate use of heat					
	Heat containment					
	Temperature requirements					
	Heat use efficiency					
	Fluid leaks					
	Heat exchange surface condition					
	Process time optimisation					
	Product loading and scheduling optimisation					
	Peak load shedding opportunity					
NETWORK	Pipe design and configuration					
	Network condition and maintenance					
	Pipe / fitting / valve insulation					
HEAT GENERATION	Water heater condition					
	Electrical element condition					
	Burner condition					
	Combustion testing and air/fuel ratio					
	Fuel quality and distribution					
	Fuel change opportunity					
	Standby losses					
	Alternative heating for smaller loads					
	Combined heat and power opportunity					
	Plant operation and scheduling					
	FD / ID fan control					
	Motor efficiency auxiliary equipment					
	Auxiliary equipment operation					
HEAT RECOVERY	Heat storage potential					
	Return loop conversion					
	Process heat recovery					
	Economiser					
	Combustion air preheating					
	Absorption cooling potential					

Appendix 4 — Measurement Accuracy Implications

When considering an overall audit accuracy requirement, the effect of cumulative measurement errors must be taken into account.

As an example, the components of the heat transfer equation are used below to demonstrate how to assess the effect of each component's accuracy on the overall accuracy:

$$q = (m/t)c_p dT$$

Where:

q = heat transfer (kW)
m = heat transfer medium mass (kg)
t = time (s)
c_p = specific heat capacity (kJ/kg°C)
dT = change in temperature inlet to outlet (°C)

The total accuracy of an equation can be expressed as:

$$\frac{\Delta x}{x}$$

Where Δx is the 'maximum inaccuracy' possible for a given absolute variable x.

For each term in the heat transfer equation, the maximum possible percentage inaccuracies are added.

$$\frac{\Delta q}{q} = \frac{\Delta m}{m} + \frac{\Delta t}{t} + \frac{\Delta c_p}{c_p} + \frac{\Delta T}{T}$$

Examples of how a percentage inaccuracy term can be evaluated are as follows:

If a data logger used for electrical power measurement has a rated accuracy of ±0.01kW and an average absolute measurement of 12kW has been recorded, maximum percentage error would be:

$$\frac{\Delta P}{P} = \frac{0.01kW}{12kW} = 0.083\%$$

Alternatively, if the data logger stated an accuracy of ±0.2%, the term $\frac{\Delta P}{P}$ would simply equal 0.2%.

Adding each term provides the total maximum possible error.

Other potential sources of error include:

- indirect temperature measurements, which may have an inaccuracy above 10%
- assessment of drive system efficiency, for example a pulley/drive-belt setup on an induced-draught fan
- assessment of a motor's efficiency

Error can be minimised by taking as many relevant measurements as practical; for example, the operation of a multiple-stage boiler could be verified by taking electrical loggings of the burner, flow loggings of fuel consumption, as well as temperature loggings of its exhaust to determine the average load.

Given that accuracy is a combination of a number of variables, the auditor needs to be aware what the main sources of inaccuracy are for the measurements and system concerned.

Appendix 5 — Definitions

There are several aspects of Process Heat systems discussed during this standard which need to be defined clearly to give context to the document. This appendix briefly outlines some concepts requiring definition. Note that this document is by no means an in-depth technical document and should only be used as a heating system subject guide for auditors.

Heating System Types

Indirect Heating System

Figure 9 shows an example of an indirect heating system. Within the context of this document, this is defined as a system that has heat generated separately, with heat distributed to heat users via a heat-transfer medium (such as water or steam).

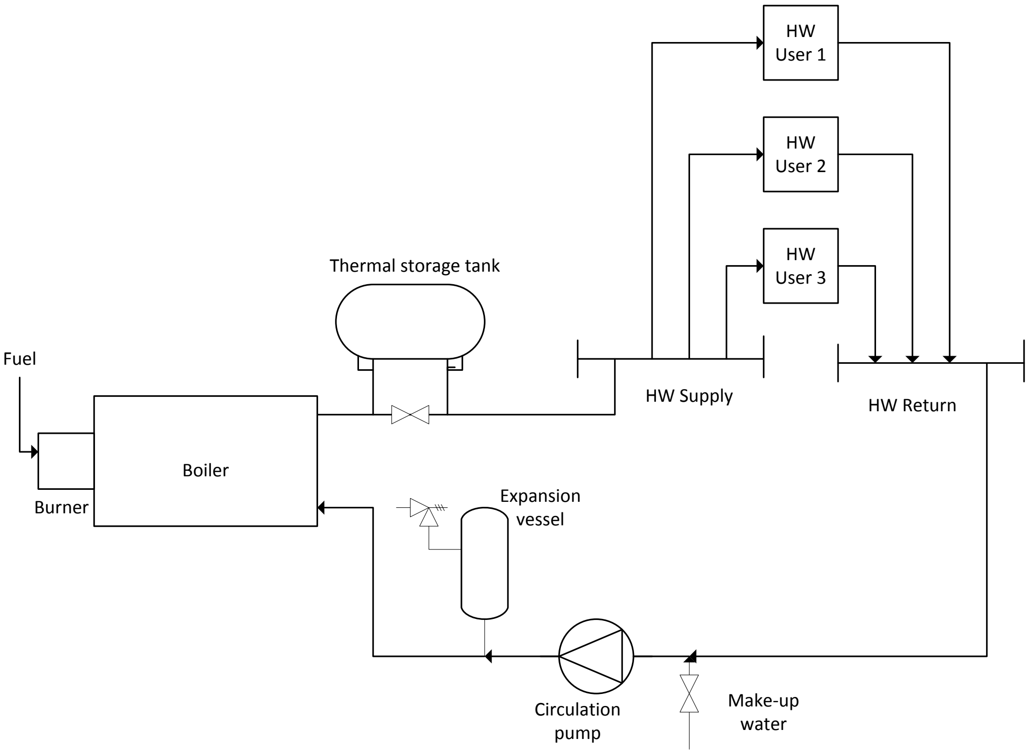


Figure 9: Indirect Heating System

An indirect heating system can be split into two further categories:

Open-Loop Heating System

An open-loop heating system has both an input and an output, with the heat-transfer medium being transported from one point to another. An example of an open-loop pumping system is shown in Figure 10.

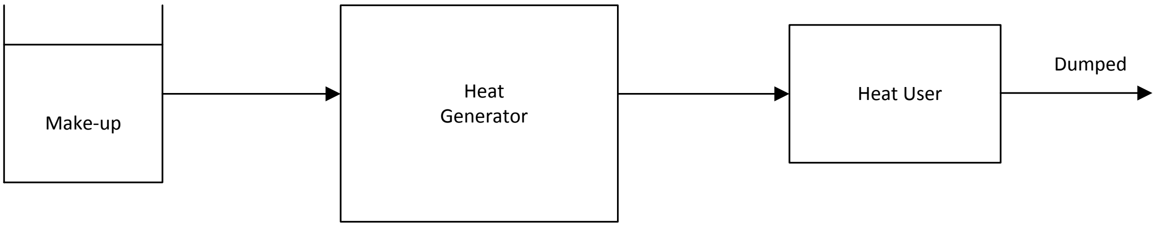


Figure 10: Open-Loop Heating System

Closed-Loop Heating System

A closed-loop heating system has a heat-transfer medium that is re-circulated around a path with the same start and end points. An example of a closed-loop system is shown in Figure 11.

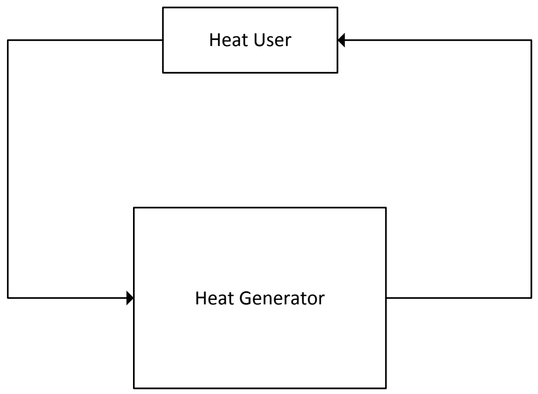


Figure 11: Closed-Loop Heating System

Direct Heating System
Figure 12 shows an example of a direct heating system. Within the context of this document, this is defined as a system that has heat generated adjacent to the heat users without the requirement for distribution via a heat-transfer medium.

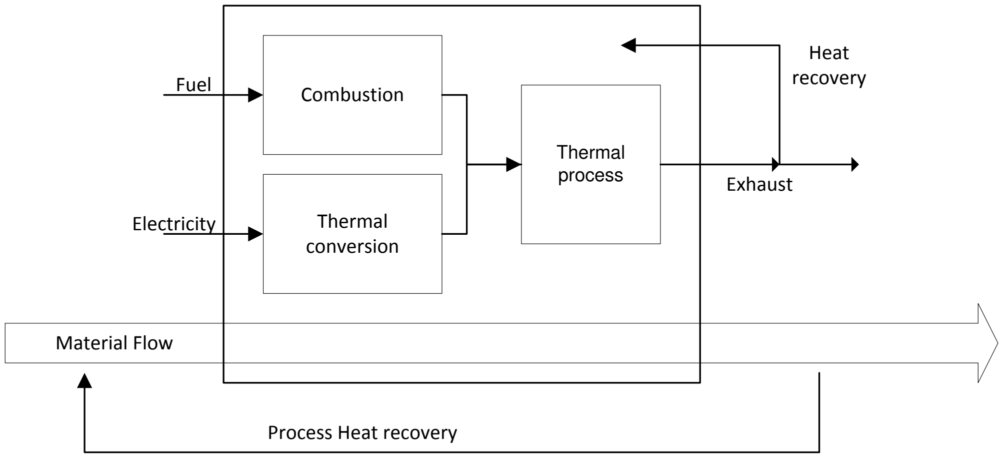


Figure 12: Direct Heating System

A direct heating system can be split into two further categories:

Batch System

Product is processed in batches. Demand for heating is variable, and there are standby time periods in which no heating is called for.

Continuous System

Product is processed continuously and the demand for heating is continuous. Although the heating demand may be variable, there are no standby periods.

Boiler Types

Firetube Boilers

In firetube boilers, the combustion gases pass inside boiler tubes, and heat is transferred to water on the outside of these tubes (shell side). An example of a firetube boiler is shown in Figure 13. Such boilers are usually cylindrical shells with horizontal tubes configured so that the exhaust gases pass through these tubes before leaving the boiler.

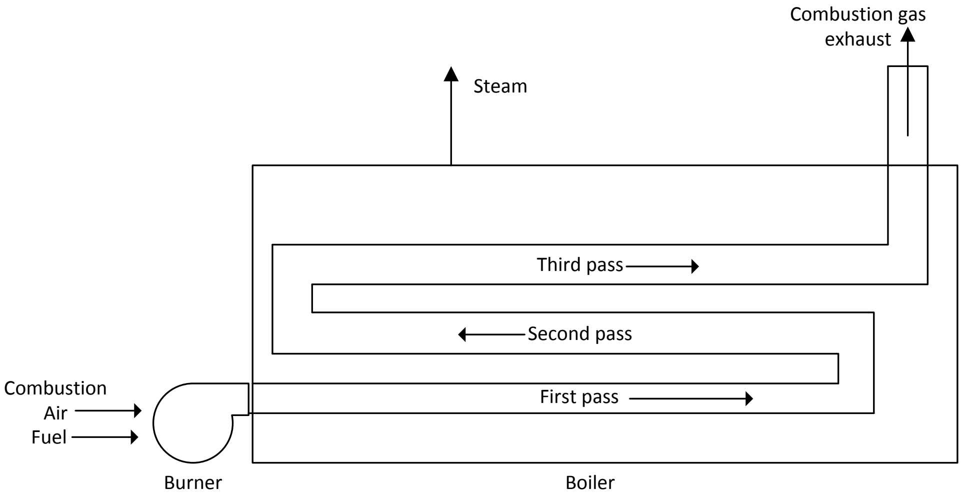


Figure 13: Firetube Boiler

Watertube Boilers

In watertube boilers, boiler water passes through the tubes while the exhaust gases pass over the tube surfaces within the shell. An example of a watertube boiler is shown in Figure 14. Since tubes can typically withstand higher internal pressures than the large shell, watertube boilers are better suited to high pressures such as for steam generation when compared to firetube boilers. Watertube boilers also generally have high efficiency because of their ability to generate superheated steam.

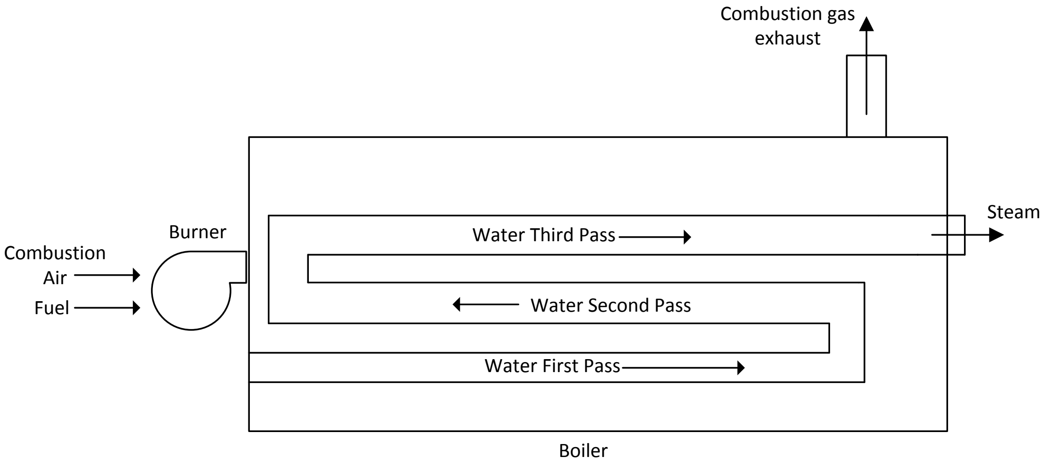


Figure 14: Watertube Boiler

Heat Transfer

There are three types of major heat-transfer methods between materials:

Conduction

Conductive heat transfer is between bodies of matter via direct transfer of heat between solid particles. The heat travels through bodies themselves, as opposed to transfer by bulk motion as is the case for convection. For liquids and gases, the convective and radiative components are the dominant means of heat transfer.

Convection

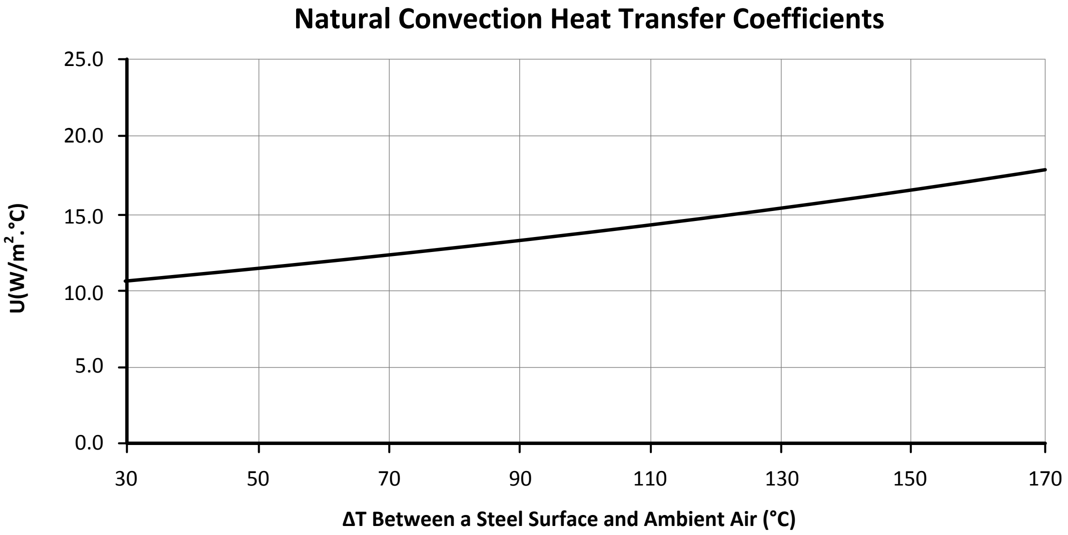
Convective heat transfer is heat that is transported from a heated surface by a fluid flowing over it, typically air. Uninsulated sections indoors will have no air moving over them; however, the temperature of uninsulated sections will warm the surroundings, causing it to move by natural convection. The rate of this heat transfer differs depending on the temperature of the sections and the ambient temperature.

Radiation

Radiation heat transfer is heat that is emitted from a high-temperature surface to the surrounding environment. The amount of heat transferred depends on the surface temperatures of the equipment and its surroundings and the emissivity of the surfaces. A lower emissivity (shiny) surface will radiate less heat than a high emissivity (dark) surface. If the uninsulated surfaces have relatively high emissivity values and temperatures, this will result in a large energy loss.

Heat Loss Analysis

Heat-loss calculations, often used for thermal imaging analysis purposes, take into account convection and radiation heat transfer from an exposed surface. Each emitting surface has a heat transfer coefficient (U or h) determined using the difference in the surface temperature of a section compared with the average ambient temperature. Graph 1 shows the heat transfer coefficient of a steel surface at varying temperature differences.



Graph 1: Heat Transfer Coefficient at Varying Temperatures

This graph gives the natural convection heat transfer coefficient of air over a steel surface, and is the value used for exposed steel sections. Outdoor sections require the use of a multiplication factor for heat loss calculations. Table 1 shows the multiplying factor at different wind speeds.

Velocity (m/s)	0	0.5	1.0	2.0	3.0
Multiplication Factor	1.0	1.3	1.7	2.4	3.1

Table 1: Effect of Air Movement on Heat Transfer

From this, the thermal resistance of air and the total heat loss from uninsulated sections can be calculated using the following formula:

$$R_{air} = R_{convection} = \frac{1}{h \times A}$$

The convective heat loss is calculated using the following equations:

$$\dot{Q} = \frac{T - T_{amb}}{R_{air}}$$

$=>$

$$\dot{Q} = h \times A \times (T - T_{amb})$$

Where:

$\dot{Q}$ = Heat transfer

h = Convective heat transfer coefficient

A = Surface area

T = Temperature of uninsulated surface

T_{amb} = Ambient air temperature

The radiation heat loss is calculated using the radiation heat transfer equation:

$$\dot{Q} = \sigma \times A \times E \times (T_{surface}^4 - T_{surroundings}^4)$$

Where:

$\dot{Q}$ = Heat transfer

σ = 5.670×10^{-8} $W \cdot m^{-2} \cdot K^{-4}$ (Stefan-Boltzmann constant)

A = Surface area

E = Emissivity

$T_{surface}$ = Absolute temperature of uninsulated surface

$T_{surroundings}$ = Absolute temperature of surroundings

Heating Generation Fuel Types

Gas

Gas is a common and convenient fuel commonly used to produce hot water and steam. Natural gas is most common, although LPG is also sometimes used when natural gas is unavailable. Burner air intake for combustion can be through natural convection or forced via fans. Gas has an advantage of being relatively clean burning, easily controllable and having a comparatively low carbon footprint. Gas heaters generally respond more easily to changing demand than an equivalent solid-fuel heater.

Electricity

Electricity is rarely used for indirect heating, but is less uncommon for direct heating. Electric heating usually consists of a resistive element, or relies on induction heat generation. Electricity is usually more expensive than gas for heat generation but has the advantage that the direct heating devices or boilers can be small and self-contained (no flues), and so are therefore able to be located close to end-users. They are also able to meet a varying load easily and can be switched on and off without efficiency penalties associated with combustion technologies.

Wood

Woody biomass can come in a variety of forms. The selection of the most appropriate form depends on the size of a boiler, available method for storing the fuel, the availability of biomass that may be generated onsite or locally, the bark content, the moisture content, and cost (usually cheap in comparison to other fuels, especially if it is the waste product of other processes).

Diesel

Diesel is generally only used for small heating plant due to its relatively high cost. However, the combustion is clean and easily controlled, fuel storage is relatively straightforward compared to many other fuels, and does not require a large volume due to a high energy density.

Fuel oil

Fuel oil is cheaper than diesel, but does not burn as cleanly due to more varied hydrocarbon molecule sizes and impurities such as sulphur and sulphur compounds. Fuel oil comes in a range of grades from light fuel oil to heavy fuel oils, which have higher fractions of crude oil. The fuel oils are often highly viscous and therefore combustion and fuel handling equipment must be specifically designed.

Coal

Coal comes in an assortment of grades from low-quality, high-moisture lignite through to anthracite, a hard coal with low moisture. Many New Zealand industrial boilers run on either sub-bituminous coal or lignite. The fuel-feed handling properties of coal are relatively good, but emissions of sulphur and high ash content can make it unsuitable for use in some applications.

Other EECA Documents

Note that there are other useful EECA documents which contain technical information in relation to Process Heat systems, including:

- Technical Guide 1.0 Introduction to Heat Exchange
- Technical Guide 8.0 Energy Efficiency Best Practice Guide, Steam Systems, Hot Water Systems and Process Heating Systems
- Technical Guide 13.0 Steam Efficiency – A Systematic Approach to Reducing Energy Wastage

Appendix 6 — Glossary of Terms

Absorption Cooling — Refrigeration process that uses a heat input to generate cooling. Suitable as an alternative to electrically driven compressor systems if the heat resource is more cost-effective than electricity.

Air Eliminator — Device that removes air from liquid systems.

Air-Fuel Ratio — The ratio of air flow to the fuel flow, which is usually based on relative volumes for gas fuels and based on relative weights in the case of liquid or solid fuels.

Air Vent — Device that removes air from steam systems.

Baseline Consumption — Estimated heating system annual energy consumption.

Boiler — In the context of this document, a vessel that converts heat from a combustion process to boil a liquid, often water to steam. The term boiler is also often used to describe vessels that heat liquids but not above their boiling point.

Boiler Efficiency — The ratio of the boiler's energy output to the boiler's energy input (i.e. the energy content of the fuel). Note that this value incorporates both the combustion efficiency and thermal efficiency of the boiler as well as the efficiency loss associated with body and blowdown losses.

Blowdown System — Boiler system removing solids that build up inside (on the water side), improving the efficiency and longevity of the boiler.

Boiler Interlock — An interlock ensures that the boiler does not operate when heating is not required. This is achieved by linking the boiler controls to the system it is supplying.

Burner — Device used to burn a given fuel for direct or indirect heating purposes, such as the direct heating within a furnace or indirect heating via a boiler.

Cascading — The use of waste heat from an initial process by an ancillary process.

Chlorides — Common salt compounds found in boiler water such as sodium chloride and magnesium chloride.

Cogeneration — Also known as combined heat and power, cogeneration involves the generation of electrical and/or mechanical work along with the thermal generation of a heating system.

Combustion — The process of burning fuel to produce heat.

Combustion Air Preheating — Using waste heat associated with industrial processes to preheat the air entering a burner, improving combustion efficiency. Typical sources of waste heat include air compressors, refrigeration condensers, mechanical cooling systems and low-grade waste heat.

Combustion Efficiency — The ratio of the burner's energy output to the boiler's energy input (i.e. the energy content of the fuel). This value gives an indication of the burner's ability to burn fuel.

Condensate — In the context of a closed-loop steam system, the condensate is water that has returned from a vapour to a liquid, releasing all of its latent heat.

Condensate Return System — System used to recollect the steam condensate and return it to the boiler, allowing the system to retain the water's sensible heat.

Condenser — In the context of a steam system, a condenser converts steam to liquid by removing energy.

COP — The Coefficient of Performance of a refrigeration system is the ratio of cooling energy output to electrical energy input.

De-aerator — Device that removes oxygen and other gases from a boiler system to prevent corrosion.

Desuperheater — Superheated steam is generally less preferred than saturated steam. Desuperheaters control the temperature of supplied steam so that it is closer to saturated steam for its end-use application.

Distributed Heating System — Refers to a set of equipment that is used to indirectly heat components used in industrial production. Common distributed heating systems include steam, hot water and thermal oil systems.

Dry-cycling — Firing of a boiler or water heater when heating is not required (preventable via boiler interlock).

Dryer — A device that removes water or other substances within a process via heating.

Duration Curve — A graph depicting the load distribution of a system.

Economiser — Heat exchanger system used to capture waste heat from a boiler/water heater's exhaust to preheat another input to the system, typically the boiler's feedwater.

Embrittlement — Loss of ductility of a material (making it brittle) which occurs in a boiler if blowdown is insufficient.

Excess Air — The remaining air after a fuel has completely combusted. This remaining air is in addition to the stoichiometric amount required for complete combustion. An air/fuel mixture that contains excess air is considered 'lean', while a mixture with less air than stoichiometric is considered 'rich'. Excess air is often described as a percentage, with 0% being stoichiometric.

Flash Steam — Occurs when a hot condensate at high pressure is subject to a low pressure and converts to saturated steam.

Flow Balance — A diagram or table showing the measured or estimated flows through different parts of a heating system.

Flue — A boiler's exhaust pipework that ejects combusted gases to the atmosphere.

Forced/Induced-Draught Burner — A burner system that operates under a mechanically forced air flow (via a forced draught fan, an induced-draught fan, or both).

Furnace — A contained space in which heat is imparted via internal combustion, electrical resistance, or chemical/nuclear reaction.

HCV - Higher calorific value of a fuel, expressed in energy content per unit of mass or standard volume. HCV includes the latent energy of water vapour in the exhaust gas.

Heat Exchanger — A system component through which heat is transferred between one medium to another, such as within a boiler where heat from combustion gases is transferred to the water.

Heat Exchanger Network (HEN) — The system of heat exchangers that recover heat from between streams, including process and utility streams.

Heat Recovery — Any form of re-use of heat that can be considered the waste heat of another process.

Heat Transfer — Heat transmission between materials via conduction, convection, or radiation.

Heat-transfer Medium — The medium by which heat is transferred from the heat-generation device to the intended heat user (e.g. steam, hot water, thermal oil, air).

Heat User — Any device relevant to business operations that requires the use of heat produced by the heating system to perform an appropriate task, such as drying.

Heating System Energy Intensity (HEI) — The energy intensity of a heating system with respect to a related key business driver, e.g. kWh per kg of production.

Hot Water Heater — A vessel that heats water but does not produce steam. The term boiler is also often used to describe such vessels, but in the context of this document the term boiler is reserved for vessels that boil a liquid.

Induction Heating — Heating that results from electrical resistance and hysteresis losses that are induced by varying a magnetic field across an electrically conducting material.

Insulation — A physical barrier to heat transfer used to minimise heat loss. A good insulating material can be considered a poor transmitter of heat.

Key Business Driver — The parameter against which the heating system's energy consumption is measured for benchmarking and monitoring purposes. This determines the Heating Energy Intensity (HEI) of the system. An example of this is production (kg).

kVA — Common unit for apparent power, which is the total power that appears to be flowing from a source to a load.

kW — Common unit for real power, which is the actual net power that is flowing from a source to a load.

Kilns — A type of enclosure typically used to fire ceramic materials or to dry wood.

Kilowatt-hour (kWh) — A unit of energy consumption equivalent to a 1,000-watt power consumption over one hour.

Latent Heat — The heat energy required to change the phase of a material at its saturation temperature, typically used with respect to the heat required to convert water from a liquid to a gas.

LCV - Lower calorific value of a fuel, expressed in energy content per unit of mass or standard volume. LCV excludes the latent energy of water vapour in the exhaust gas.

Make-up Water — Outside water brought into a system to replace any lost water. In the case of a steam system, this replaces lost condensate, water removed in blowdown, and water lost via steam leakage.

Microwave Heating — Microwave systems use electromagnetic radiation to excite water molecules, or produce heat in a susceptor.

Modulating Burner – A fuel burner that adjusts its heat output in proportion to the end-user demand.

Motor Efficiency — The motor efficiency is defined as the energy delivered from the motor to its coupling divided by the energy delivered to the motor.

Ovens — Similar in most respects to a furnace, though the term 'oven' usually refers to processes such as cooking, baking, stoving, curing and annealing.

Peak Load — The peak power consumption of a site. This often determines the demand charges incurred by the site and should therefore be taken into account when considering the operating times of electric heating systems.

Plasma Arc Heating — An electric arc between electrodes ionizes gas (known as plasma) and in so doing heats the gas.

Power Factor — Ratio of real power to apparent power.

Resistance Heating — Heat generated by passing electrical current through a resistor, causing it to increase in temperature and emit heat.

Sankey Diagram — Flow diagram depicting the energy flows through a system. The width of each arrow is proportional to the relative size of each flow.

Saturated Steam — Steam that is at the boiling temperature for water at a given pressure.

SCADA System — Supervisory Control and Data Acquisition system

Sensible Heat — The heat associated with raising the temperature of a substance without phase change.

Separator — Separators remove condensate and air from a boiler system to improve steam quality and reduce corrosion.

Silica — A steam-soluble element found in water (typically in the form of silicon dioxide) that forms a scale which acts as an unwanted insulator and can also erode surfaces.

Single-Stage — A burner that has only 'on' or 'off' control.

Specific Heat — Amount of heat required to raise a substance's unit weight by a degree Celsius (°C) under a specified temperature and pressure.

Standby Losses — With respect to a direct or indirect heating system, the standby energy losses are losses associated with natural heat loss or electrical energy consumption when the system is in standby mode.

Steam Accumulator — Steam storage vessel that helps alleviate a boiler’s operation during high-demand periods.

Steam Trap — Removes condensate from a steam system network while preventing steam leakage.

Stoichiometric Ratio — The theoretical ratio of air to fuel under which an air/fuel mixture is capable of complete combustion with no unused fuel or air (excess air = 0%).

System Efficiency — The ratio of useful energy consumption required by the system divided by the total energy consumed by the heating system.

Thermal Efficiency — The ratio of a heat exchanger’s output energy to input energy. In the case of a boiler this refers to the boiler’s ability to transfer heat from the combustion gases to the water or steam in the boiler.

Thermocompressor — A device using a high-pressure steam flow to increase the pressure of a low-pressure steam flow.

Throttle — Device, such as a valve, that is used to restrict flow by increasing frictional resistance (increasing dynamic head).

Two-Stage — A burner that has a low-firing and high-firing setting that can be varied depending on demand.

Turndown Ratio — The ratio of a heater's heat output capacity to the minimum heat output it can operate at before it switches off.

Utility Targets — An achievable utility performance limit, determined prior to design.

Variable Speed Drive (VSD) — A variable speed drive (VSD) is a system for controlling the rotational speed of an alternating-current electric motor through adjusting the electrical frequency supplied to the motor. VSDs usually have inbuilt PID controllers which allow them to automatically adjust their speed based on a digital input signal.

Water Treatment — Water treatment refers to the planned treatment of water within a system to improve the efficiency of the boiler by reducing the amount of blowdown, and increasing the life of equipment.

Appendix 7 — Recommended Report Outline

This appendix provides a recommended outline of the structure and contents of the report used for reporting of the process, findings and recommendations from an audit, conducted according to this Process Heat Systems Audit Standard.

The following describes the recommended structure and content of the audit report, section by section.

Executive Summary

Provide here a summary of the objectives, scope, findings and recommendations.

In particular, this should highlight the key recommendations for the client to action and a rationale for action that is concise, understandable and compelling – recognising the client's decision-making processes.

Tabular (and possibly pie chart) presentation of the annual saving and net present value available from pursuing each recommendation can be useful.

1. Business Context

This section should cover basic information about the business and the objectives and scope of the audit.

Basic information

Include here the:

- identity of the client and site location for which the audit is performed;
- date of the heating systems audit
- name of the client manager and other key personnel interfacing with or assisting the heating system audit;
- name, credentials and contact details of the heating system auditor.

Site operating characteristics

Describe here the operating characteristics of the site, including:

- a brief outline of the current operations of the plant, with description of the main site activity that the heating systems are required to support;
- the effects of any expected future changes to the nature or volume of the site activity that may have an effect on the site heating system requirements.

Objectives and scope of the audit

Describe here:

- the objectives of performing the audit. For example, It may be to provide the client's management with a general understanding of areas of potential (as would be expected from a base-level audit) or it may be to support a capital expenditure proposal on a substantial refurbishment or redesign;
- the scope of the audit. This may range from being one component of one heating system or full systems audits of all heating systems on the site.
- any useful background to the objectives and scope, including any prior scoping work and key clauses from any agreement between the client and the auditor;

2. *Heading System Overview*

Include a high-level description of the system and identification of the business drivers and the means by which the audit results can be extrapolated to annual operating characteristics.

Description and requirements

Include a description of the heating system(s) and its configuration, with reference to schematic drawings in an appendix to the report.

Describe the requirements that the business expects from the audit, including:

- a description and quantification of energy flows throughout the system. Pie charts or Sankey diagrams are generally useful for depicting these quantities;
- a description and quantification (temperature, flow, and pressure) of what the heating system(s) need to deliver to enable the business to operate efficiently;
- identification of the site activity (e.g. production output or raw material input) that will be used as the key driver of heating system use and that will be used in the energy intensity measure for the heating system;
- identification of whether the heating system requirements can be characterised as constant demand, multi-stage demand or variable demand;
- information on the operating profile of the main site activity (e.g. volume of production), showing weekly and monthly/seasonal profiles; and
- any relevant benchmark information that may be available from site history or from intercompany comparisons on the heating system's energy intensity.
- description of any management policies or practices (e.g. safety or community matters) that influence the heating system design or operational requirements.

Baseline energy intensity

This involves quantification of the relationship between the site activity (e.g. production output or raw material input) identified as the key driver of the heating system and the system's energy usage, using the daily data collected during the audit period.

This should include the:

- method for quantifying the daily site activity driving the heating system energy usage;
- method for quantifying the daily kWh usage from the heat-generation devices via data loggings or other measurements taken during the audit, and;
- the audit-period average and (where feasible) each day's value of the heating system energy intensity value (the baseline HEI) for the period of the audit.

Having each day's value of the HEI relationship may enable the effect of variations in activity level on the HEI to be quantified and included in any subsequent analysis of the system where the activity level is different from the average during the audit period. The relevance of the individual days' HEI figures will be dependent on the driver and the ability to obtain activity levels of sufficient accuracy at a daily level.

If the client considers activity figures too commercially sensitive for inclusion in the report, include only the baseline HEI

3. *Audit Measurement Methods*

This section should cover the measurement methods used during the audit and identify (and rationalise) any variations between the actual measurement methods and those recommended in the Audit Standard.

Energy usage measurement

Include a description of electricity and fuel use measurement methods used for the audit period, including any metering installed for subsequent (post-implementation) performance monitoring and the extent of any reconciliations performed between temporary and permanent meters.

For each heating system involved, describe:

- the metering and data-recording methods used, and the units measured;
- the equipment data-logged; and
- the period(s) and duration(s) of the measurements.

Energy cost measurement

Describe the method of quantifying the unit cost of electricity or fuel as appropriate for valuing any reduced consumption resulting from implementing a recommendation.

Costs should be based on future price expectations and for electricity consumption recognise the fixed and variable (per-kWh) components of delivered electricity prices. Where the client is subject to time-of-use and/or peak demand pricing, consideration should also be given to the time periods in which the systems operate, and therefore in which any energy savings are likely to occur. These considerations are most relevant when the audit results are to be used for investment proposal purposes.

Pressure measurement

Include here:

- a description of the pressure and pressure difference measurement methods used for each of the measurement point locations;
- the method and currency of the calibration of the pressure measurement instruments;
- identification of where pressure differences are estimated, the method of estimation and reason for estimation.

Flow measurement

Include here information on:

- the location and timing of any flow measurements taken;
- the flow measurement method and technology employed (intrusive or other);
- the method and currency of the calibration of the pressure measurement instruments; and
- identification of where flows are estimated, the method of estimation and reason for estimation.

Also, in the case of fuel flow measurement, include details of any metering installed for subsequent (post-implementation) performance monitoring.

Temperature measurement

Include here:

- the location and timing of temperature measurements;
- the temperature measurement method and technology employed (e.g. thermometer, thermocouple);
- a description of the temperature and temperature difference measurement methods used for each of the measurement point locations;
- the method and currency of the calibration of the temperature measurement instruments;
- details of any temperature loggings taken;
- identification of where temperatures are estimated, the method of estimation and reason for estimation.

Measurement of leakage and inappropriate use

Describe here how the heat loss from leakage and inappropriate uses was identified, and how the energy use of potential alternative technologies and energy sources is quantified.

Measurement of heat losses

Include here:

- the location and timing of thermal images;
- a description of the thermal imaging technology used;

- a description of the thermal imaging methodology.

Estimates of implementation costs

Provide here the method or methods used to estimate the costs of implementing the actions included in the recommendations. This should include:

- the sources of the cost estimates;
- the level of accuracy that can be expected; and
- whether or not any preferred suppliers are involved.

4. *Audit Findings*

For each of the systems within the scope, this section should describe, analyse and quantify opportunities for efficiencies in a logical sequence from demand through to distribution network, generation and finally heat recovery. Discussion of opportunities for change should include consideration of other viable options along with the recommended action.

For each recommended action, there should be:
- a description of the efficiency opportunity;
- transparent calculations of the energy and other savings potential;
- a cost estimation of implementing the proposed action;
- a simple payback period (or other net benefit measure) quantified and shown, as applicable to the audit scope / accuracy requirement;
- identification of any alternatives to the recommended action; and
- identification of dependencies, where a particular recommendation may be dependent on the implementation of some other recommendation or other plan

The detailed cost-benefit calculations that support each recommendation should be included as part of an appendix.

Heating system demand side

From the measurements of temperature, flow and pressure at key points of demand on the heating system, and from the demand profiles taken of heat-energy-consuming equipment, discuss the various opportunities relating to system features driving demand.

Peak load trimming or shifting
Include here a description of any opportunities related to trimming or shifting of peak electrical heating demands.

Inappropriate end uses
Identify and describe the applications where the heating method is not the most appropriate (energy-efficient) means of achieving the business purpose.

Isolation opportunities
Identify and describe the applications where the heat users can be isolated (heat transfer suspended) between their operating periods.

Pressure reduction
Identify and describe the applications where the localised pressure can be reduced.

Temperature reduction
Identify and describe the applications where the localised heating can be reduced. This may be achieved by such initiatives as improving heat exchanger condition or improving product handling methods.

Leakage
Identify and quantify the amount of leakage, and specify the priorities in terms of leak repairs and prevention.

Heating system distribution network

Pipework condition and configuration

Describe the audit findings relating to:
- the physical condition of the network;
- any pipework features significantly notable impacting on demand; and
- pipework maintenance practices.

For each of the above main findings:

- quantify the effects on pressure and/or flow associated. For example, quantify the pressure losses resulting from the condition of the particular configuration, constrictions, length or corrosion feature.

Insulation
Identify and quantify heat loss associated with uninsulated network sections, and specify the priorities in terms of insulation installation/repair.

Steam trap condition (for steam systems only)
Include a discussion on the condition of steam traps. Quantify the effects on the system associated with poor maintenance of the steam traps. Identify and quantify the amount of steam leakage, and specify the priorities in terms of leak repairs, prevention and ongoing timely (efficient) detection.

Valves and separators

Include a discussion on where any valves and/or separators being used, and the purpose of their use. In addition, quantify the effects on pressure and/or flow associated with the use, misuse or poor maintenance of valves.

Where a recommendation is made include a description of the network component concerned, the effect of the recommendation on pressure and/or flow, a budgetary cost of the solution and the payback for the client.

Pipework sizing

Include here the audit findings relating to pipe sizing. In particular, identify:

- the extent and location of undersized pipework;
- the effect on pressure and/or flow of each incorrectly sized section of pipework.

This information should lead to calculations of potential savings, and identification and costing of cost-effective solutions.

Heating system generation side

The generation side of the heating system (the burner, boiler and fuel system) delivers demand that is the sum of the productive requirements of the business as well as the demand from sub-optimal uses and waste.

This section of the report should focus on the supply-side solutions that are economic once the downstream demand has been specified, net of the demand from sources that will be eliminated by the economic solutions specified in earlier recommendations.

The demand profiles obtained from the electrical, temperature or flow loggings, and the analysis conducted on the downstream demand drivers, should provide the basis for identification of the supply-side opportunities.

Combustion efficiency

Using burner design information and relevant available combustion efficiency data, describe the current combustion efficiency (not applicable in the case of electric resistive heating) and any initiatives to improve the efficiency.

Heat generation device demand characteristics

Provide a summary (e.g. a table) of the key information collected and derived from temperature, flow or electrical data-loggings and any other metering of the heat generation device over the audit period.

This information should include: average power loading (kW)[6] and a description of any heating control methods. The logging records should be included in an appendix to the report.

Plant control

Include description of initiatives related to heat generation control systems. This includes initiatives related to burner control systems, water treatment systems, and capacity control systems.

Auxiliary equipment operation

Include description of initiatives related to the control of auxiliary equipment such as circulation pumps or induced/forced-draught fans. Note that analysis of such pump or fan systems are covered in other system standards.

Insulation

Identify and quantify heat loss from the bodies of heat-generation devices, and specify the priorities in terms of insulation installation/repair.

Heating system heat recovery

This section of the report should focus on potential heat recovery solutions that are economic once the downstream demand has been specified and the generation system has been optimised.

Heat storage potential

Include here description and quantification of heat storage measures that will capture heat that would otherwise be lost to the surroundings.

Heat generation heat recovery

Include here the audit findings relating to heat recovery from within the heat generation systems. In particular, identify:

- the amount of potential heat that can be recovered;
- the type of heat recovery (e.g. condensate return, flash steam heat recovery, and exhaust gas economising);

Waste heat recovery

Include here the audit findings relating to waste heat recovery. In particular, identify:

- the amount of potential heat that can be recovered from other utilities (e.g. air compressors or refrigeration system compressors);

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[6] Average power is the weighted average kW value calculated during plant operating hours, and is independent of the method of control.

- applicable heat use such as combustion air or feedwater preheating.

5 *Ongoing Performance Monitoring*

In this section of the report, consider and recommend what ongoing heating system performance measurement systems should be put in place by the client.

Recognising the need to measure energy consumption of each heat-generation device to establish the baseline HEI, the recommendations here in relation to fuel or electricity monitoring should be influenced by the metering decisions taken at the commencement of the audit and discussed earlier.

The Audit Standard outlines the options for ongoing fuel or electricity usage metering.

6 Summary of Recommendations

Include a summary table of the actions recommended, drawing from all previous sections. An example is shown below.

Recommendation Identifier and Report Section Ref	Depend-ency[7]	Electricity Saving (kWh p.a.)	Other Fuel Savings (kWh p.a.)	Annual cost saving ($)	Implementation Cost ($)	Simple payback period (years)
Demand-side recommendations						
Rec #1 Sec x.x.x						
Rec #2 Sec x.x.x						
Network recommendations						
Rec #3 Sec x.x.x						
Rec #4 Sec 4.x.x						
Heat generation recommendations						
Rec #5 Sec x.x.x						
Rec #6 Sec x.x.x						
Heat recovery recommendations						
Rec #7 Sec x.x.x						
Ongoing monitoring recommendation						
Rec #8 Sec x.x.x						

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[7] Dependency: meaning that any recommendation that to be viable is dependent on some other action, must be identified as being dependent on that other action, and some identification of that action must be provided.

7 Appendices

The appendices should include:

1. Schematic of each of the heating systems
2. Audit data records, including relevant logging records, for temperature, electricity, pressure and flow.
3. Heat Leakage reports containing thermal images taken whilst onsite (if applicable), along with detailed descriptions of the location of each surface and estimated heat loss
4. Cost-benefit details of options and recommendations

In relation to the cost-benefit details, particularly where the audit will be used to support business investments, the relevant appendix should provide a summary of the data and calculations performed for each option and recommendation. In addition, this should be accompanied by:

- any supplier or installer quotations that support the implementation cost estimates, and any assumptions that could materially affect the accuracy of the payback period; and
- where there are the several options for the same outcome, clear flagging of the options as being mutually exclusive.

This level of detail can be important to the subsequent development of an investment proposal.