SUSTAINABLE ENERGY AUTHORITY OF IRELAND

A good practice guide for energy performance indicators for utilities

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About SEAI

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with Government, homeowners, businesses and communities to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of Communications, Climate Action and Environment.

The large Industry Energy Network

The Large Industry Energy Network is one of the world's leading energy efficiency networks, made up of prominent organisations operating in Ireland, all working towards a strategic approach to energy management. Some 200 of Ireland's largest energy users are members of the network and together they account for 55% of Ireland's industrial Primary Energy Requirement. Network members are companies with annual energy bills of €1 million or over. Supported by SEAI, they work together to improve their energy performance and inspire others to follow.

A special working group was established to address energy use in a variety of utilities. This special working group worked on a number of projects, one of which was a review of best practice for energy performance indicators.

Executive summary

The purpose of this guide is to document current best practice with regard to the energy performance indicators normally used to manage the following utilities systems effectively:

- Chilled water systems
- Compressed air systems
- Combined heat and power (CHP) generation systems
- Gas boilers for hot water generation.

These four systems are commonly in operation on manufacturing sites, and as such, their efficient operating procedures should be highly replicable across the industry.

Chilled water systems

It is recommended to implement the coefficient of system performance metric as the energy performance indicator for chilled water systems. This metric divides the useful thermal energy generated by the chilled water system by the total electrical input requirement of the system, and as such, relates generated energy to delivered energy. This total energy requirement is not limited to the chillers themselves, as it also takes into account the pumping and cooling tower energy required, thus lending itself to a truer reflection of chilled water system generation performance. The data required to calculate this metric are available via the site building management system; however, these data must be automatically transferred to the site monitoring and targeting system to substantiate this analysis.

Compressed air system

It is recommended to implement a new metric that takes in both the compressed air generation and the normal metres cubed of compressed air generated (kWh/Nm^3). A compressed air header flow meter is available on eSight (http://www.esightenergy.com/), although some normalisation is required to convert this to Nm^3 using available building management system meters) or assumptions.

CHP generation system

An energy performance indicator should be established to determine the performance of a CHP system in a more accurate manner. As a result, the total system efficiency would be implemented, thus allowing a comparison of the energy produced (the sum of electricity and heat) to the energy input required to generate this. Once validated, the effective electric efficiency of the system can be calculated using the information already gathered on eSight, and is a better method of monitoring the system when carrying out comparisons to alternative electrical generation systems.

Gas boiler for hot water generation

The fuel-to-water efficiency of a boiler should be determined using an input-output method; this compares the amount of useful heat added to the water with the amount of energy input to the system in the form of fuel. The resulting metric is a percentage value for the system’s efficiency. The data are available via the site building management system, but again they must first be transferred automatically to the site monitoring and targeting system to facilitate ongoing analysis.

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1 Energy performance indicators

An energy performance indicator is a standard or point of reference against which comparisons can be made. It is a valuable tool, through the process of benchmarking, for assessing energy performance. [1] The establishment of an energy performance indicator (EnPI) can enable an accurate assessment of performance and can aid in decision-making aimed at improving performance.

An energy performance indicator can be applied at a range of levels, from the whole facility to an individual piece of equipment. The scope of the indicators established in this report are for whole systems, which are part of the utilities on site. Each system is a collection of plant equipment that provides a particular requirement for the site.

The establishment of an energy performance indicator can enable the monitoring of cost, energy consumption or environmental performance. The primary focus of the indicators established in this report is on monitoring performance based on the energy consumption of the systems being examined. As financial and environmental performance is related to each system's consumption, these can be deduced from the established energy performance indicators.

Once an energy performance indicator is established, it is important to be able to make comparisons against similar references to indicate how well the relevant system is actually performing; these references can be either internal or external. Internal sources of reference typically analyse and compare the indicator to past performance of the same system. Comparison with historical performance may not be possible in some cases where the establishment of an indicator requires the installation of additional metering for the system. A comparison against established best-practice benchmarks is considered to be an external reference. The aim of the energy performance indicators established in this report is primarily to enable comparison with external best-practice references, which are considered to be the best in industry. Once indicators are established for each system, it is possible to make comparisons in the future based on internal benchmarks over various timescales.

The main body of this report reviews the indicators available for each system, which have been used by industry to monitor energy performance. The utilities systems that have been reviewed include:

- Chilled water systems;
- Compressed air systems;
- Combined heat and power (CHP) generation systems; and
- Gas boilers for hot water generation.

Recommendations are made to indicate which energy performance indicators are most suitable for implementation on site, based on information available from disparate systems. An analysis is carried out on the information to generate the desired energy performance indicator, with gaps between current state and best practice detailed.

2 Chilled water systems

2.1 Review of indicators for chilled water systems

2.1.1 Energy efficiency ratio and full load efficiency

The energy efficiency ratio is the ratio of the cooling capacity to the power input of the unit. It is a measure of how efficiently a cooling system will operate under application-specific conditions when the outdoor temperature is at a particular level. The higher the energy efficiency ratio, the more efficient the air conditioner is. This ratio only covers the performance of the unit under one specific condition, which it might only operate at for 1% of the time, and is not suitable for use on a system that is in operation. This ration is more suited to rating a chiller system prior to installation. Another indicator that is very similar to the energy efficiency ratio is full load efficiency, which is measured in kW/ton. Full load efficiency has the same limitation as that outlined for the energy efficiency ratio [2], [3].

2.1.2 Integrated part load value, applied part load value and non-standard part load value (PLV)

Chillers rarely operate at their full rated cooling capacity. Therefore, calculating chiller efficiency based on full load efficiency is not a true representation of the system's efficiency. Integrated part load value is a metric that attempts to improve the accuracy of measuring overall chiller efficiency by assuming the chiller will operate over a range of conditions during operation. These assumptions are that the chiller operates as follows [2]:

- 100% load: 1% of operating hours;
- 75% load: 42% of operating hours;
- 50% load: 45% of operating hours; and
- 25% load: 12% of operating hours.

The integrated part load value is the weighted average cooling efficiency at part-load capacities related to a typical season rather than a single rated condition. It is, like full load efficiency, measured in kW/ton. The calculation of the value uses standard rated conditions outlined by the Institute of Refrigeration Ireland instead of actual operating temperatures.

Applied part load value is calculated in the same way as integrated part load value but uses actual operational temperatures, which makes it a more realistic metric. Non-standard part load value is a revised version of applied part load value that uses different assumed operation ranges to try to provide a more realistic model of off-design performance [2].

The three values detailed that measure chiller efficiency are improved versions of the energy efficiency ratio or full load efficiency, but they still do not account for actual operating conditions. These values are, again, more suited to the rating of chiller systems prior to installation, so that comparison can be made, but not when systems are in operation.

2.1.3 Coefficient of performance

The coefficient of performance can be used to calculate the efficiency of chilled water systems. It is essentially the refrigeration energy generated by the chiller system divided by the electrical energy consumption of the compressor. Therefore, the coefficient of performance is the ratio of heat removal to the energy input to the compressor [2]. The electrical consumption of associated fans and pumps is not accounted for when determining the coefficient of performance of a chiller system.

$$\text{Coefficient of performance} = \frac{\text{Useful refrigeration effect}}{\text{Energy consumption of compressor}} = \frac{Q}{E_{comp}}$$

Where:

$$Q = mc\Delta T$$

- m = mass flow rate (kg/s)
- c = specific heat capacity (kJ/kgK)
- ΔT = temperature difference (K)

The coefficient of performance is a measurement of efficiency; the higher the number, the more efficient the system is. The coefficient of performance is dimensionless because the input power and output power are measured in kW. The coefficient of performance is also an instantaneous measurement in that the units are power, which can be measured at one point in time [4]. The required metred values are the electrical consumption of chillers, flow and return temperatures and flow rate to or from the chiller (these values should be equal).

2.1.4 Coefficient of system performance

The coefficient of system performance is similar to the coefficient of performance, but it attempts to account for the total consumption of the whole refrigeration plant by including the electrical consumption of the chilled water distribution system and auxiliary loads. Hence, the coefficient of system performance includes the additional power consumption of ancillary but necessary equipment such as pumps and fans, as indicated in the following equation:

$$\text{Coefficient of system performance} = \frac{\mathrm{Q}}{\mathrm{E_{comp}} + \mathrm{E_{fan}} + \mathrm{E_{pump}} + \mathrm{E} \ldots \ldots \ldots}$$

Again, both the useful refrigeration effect and the total electrical consumption have units of kW and the resulting calculation is expressed as a ratio, with a higher coefficient of system performance indicating a more efficient system. The required metred values are the same as those for coefficient of performance, but additional electricity metering is required. Electrical loads that should be measured are chiller system input, chilled water distribution pumps input, cooling tower fans input, and ancillary users input (such as cooling tower water pumps and other small users) [5].

2.2 Commentary on energy performance indicators suitable for monitoring chilled water (CW) performance

As outlined in the previous section, many of the metrics discussed are more suited to measuring systems prior to installation by assuming operating conditions. The coefficient of performance and coefficient of system performance metrics are instantaneous forms of measurement; the units used in calculation are units of power, which can be measured at one point in time. This makes both measures suitable for continuous monitoring of chiller system performance using real operating conditions obtained through metering.
The required metred values for finding the coefficient of performance are the electrical consumption of the chillers, the flow and return temperatures, and the flow rate to or from the chillers. The required metred values for the coefficient of system performance are the same as those for the coefficient of performance, but additional electricity metering is required. The coefficient of system performance is a more accurate representation of the whole system's efficiency.

2.2.1 Considerations

When using the coefficient of system performance instead of the coefficient of performance, metering of the most significant energy users within the system is vital; namely the compressor motor, the distribution pumps and the condenser fans. The energy consumption of auxiliary pumps (and any other small loads) should be much lower in comparison. The more auxiliary loads that are metred, the more accurate the final value for coefficient of system performance will be.

Ideally, the coefficient of system performance should be used in a system that uses variable-speed pumps. Fixed-speed pumps may result in the introduction of a significant static portion to the equation. If installed meters are related to fixed-speed pumps in the system, it may be necessary to exclude these loads from the calculation. This would result in a less accurate figure, but it would indicate a better relationship between plant items which can be varied, as the inclusion of fixed-speed pumps introduces a static portion to the equation that cannot be altered.

2.2.2 Best practice Indicator for chilled water systems

It is recommended to implement the coefficient of system performance metric as the system energy performance indicator for chilled water systems. This metric divides the useful thermal energy generated by the chilled water system by the total electrical input requirement of the system, and as such, relates generated energy to delivered energy. This total energy requirement is not limited to the chillers themselves, as it also takes into account the pumping and cooling tower energy required, thus lending itself to a truer reflection of chilled water system generation performance. The data required to calculate this metric are available via the site building management system; however, these data must be automatically transferred to the site monitoring and targeting system to substantiate this analysis.

3 Compressed air system

3.1 Review of indicators for chilled water systems

3.1.1 Pressure

Power consumption in the compressor, as well as unregulated compressed air flows, increase with discharge pressure [6]. Measurement of the pressure differential across filters and dryers is an important indicator of system efficiency and is a maintenance-related condition. Increased pressure differentials will lead to reduced system performance and may require cleaning/maintenance. To determine the overall performance of the compressors and the distribution network, it is necessary to gain an understanding of the pressure at strategic points throughout the system; these pressure readings can be used to form an energy performance indicator for the system. SEAI guidelines state that pressure readings should be taken at strategic points throughout the system. These are [7]:

- At compressor discharge points;
- Before and after filters;
- Before and after dryers;
- At the main distribution header; and
- At critical users.

Pressure readings at strategic points can be used to estimate losses, which relates to the overall performance of the system.

3.1.2 Power

The monitoring of power consumption (in kW) in a compressor system by measuring the electrical load to each compressor can be used as an energy performance indicator [6]. These measurements allow the calculation of cost for running the system, but are limited, as they do not account for the variation in power consumption with varying amounts of compressed air production.

3.1.3 Flow

The measurement of compressed air flow, in m^3 (which should be normalised to Nm^3), in a system is a basic energy performance indicator. It is difficult to estimate the amount of compressed air being generated by a compressor when there are complex variable capacity controls involving air receivers in the system [6]. Flow measurements leaving individual compressors, as well as main distribution headers, can enable an accurate estimate of the amount of air being generated by a system involving multiple compressors and receivers. Using flow as an energy performance indicator is limited; when used alone, the measurement of flow does not account for the demand on the system or for the varying energy input to the system.

3.1.4 Relationship between power and flow

The most apparent way to determine the performance of a compressed air system would be to monitor the amount of energy required to produce a particular amount of compressed air – or, vice versa, to monitor the amount of compressed air produced per unit of energy input. There are a number of energy performance indicators available that attempt to monitor this relationship effectively. These include, but are not limited to, kW/m^3/min, kWh/m^3, and kW/L/s. According to SEAI, the most common energy performance indicator for a compressed air system benchmark is the ratio of energy consumed per normal metre cubed of compressed air (kWh/Nm^3) [7]. The normalisation of the volume of compressed air to a standard pressure and temperature is important; this is because the use of the simple m^3 does not accurately reflect air production, as the volume of air varies with pressure and temperature. The electrical power consumption of the system is required; this is commonly taken to be the consumption of all compressors in the system.

$$\text{Energy performance indicator} = \frac{Electrical\ input\ to\ compressors\ (kWh)}{Compressed\ air\ produced\ (Nm^3)}$$

3.2 Commentary on energy performance indicators suitable for monitoring compressed air system performance

kWh/Nm^3 is the most suitable single energy performance indicator for the performance of a compressed air system on site. This indicator considers the amount of compressed air being produced by the system and compares it to electrical consumption, which makes it possible to monitor the system's energy performance.

The use of this indicator requires the metering of electrical input to compressors, the flow rate of compressed air produced, and the associated readings for temperature and pressure to determine the flow rate in normalised metres cubed (Nm^3).

3.3 Best practice indicator for compressed air systems

It is recommended to implement a new metric that takes in both the compressed air generation and the normal metres cubed of compressed air generated (kWh/Nm^3). A compressed air header flow meter is available on eSight (http://www.esightenergy.com/), although some normalisation is required to convert this to Nm^3 using available building management system meters or assumptions.

4 CHP generation system

4.1 Review of indicators for CHP systems

4.1.1 Electrical and thermal efficiencies

The electrical efficiency of a CHP system indicates the amount of electrical power generated per unit of energy input to the system. The following equation outlines the appropriate calculation:

$$E_E = \frac{Useful\ electric\ output}{Energy\ input} \times 100$$

The energy input to the CHP system is found by measuring the fuel input to the system and applying a known heating value to the fuel. The electrical efficiency is expressed as a percentage of the energy input which is output.

The thermal efficiency is a measure of the usable heat generated by the system unit of energy put into the CHP system. The following equation outlines the appropriate calculation:

$$E_T = \frac{Usable\ heat\ generated}{Energy\ input} \times 100$$

The energy input is again found as outlined previously. The thermal output is calculated using the following formula:

$$Q = \mathrm{mc}\Delta\mathrm{T}$$

Where:

- Q = usable heat generated (kW);
- m = mass flow rate (kg/s);
- c = specific heat capacity (kJ/kgK); and
- ΔT = temperature difference (K).

The thermal efficiency is again expressed as a percentage of the energy put in which is output as usable heat.

The electrical and thermal efficiency of a CHP system can each be used individually as an energy performance indicator to monitor performance, but individually cannot represent how the system is performing overall.

4.1.2 Effective electric efficiency

Effective electric efficiency calculations allow for a direct comparison of CHP to alternative power generation systems; this is typically grid-supplied electricity. The following equation is used to calculate the effective electric efficiency of a CHP system as a percentage [8], [9]:

$$E_{EE} = \frac{W_E}{Energy\ input - \frac{Q}{\alpha}} \times 100$$

Where:

- W_E = useful electric output (kW);
- Q = usable heat generated (kW); and
- α = efficiency of technology that would otherwise be used to produce thermal energy.

For example, if a CHP system is natural-gas fired and produces steam, then α represents the efficiency of a conventional natural-gas-fired boiler. The calculation of effective electric efficiency is essentially the CHP system's net electric output divided by the additional fuel the CHP system consumes, over and above what would have been used by conventional systems to produce the thermal output for the site. In other words, this metric measures how effectively the CHP system generates power – once the thermal demand of a site has been met [8], [9].

4.1.3 Fuel charged to power

The fuel charged to power of a CHP system is a metric that can be used for comparison to other electricity-generation methods [10]. This energy performance indicator is the inverse of effective electrical efficiency, which is outlined in the previous section.

$$\text{Fuel charged to power} = \frac{Energy\ input - \frac{Q}{\alpha}}{Electrical\ power\ generated}$$

Fuel charged to power serves the same purpose as effective electrical efficiency, the only difference being that the resulting indicator is a number rather than a percentage; a value of 1 corresponds to 100% effective electrical efficiency. Again, it is a useful metric for comparison of a CHP to an alternative electricity-generation method (the grid).

4.1.4 Total system efficiency

The total system efficiency is an energy performance indicator that can be used to monitor the overall performance of a CHP system. It removes the limitations of calculating electrical and thermal efficiency individually and it essentially combines these two measures. The total system efficiency of a CHP system is the sum of the net useful electric output and the net useful thermal output divided by the total fuel energy input, as shown below [8]:

$$E_T = \frac{W_E + Q}{Energy\ Input} \times 100$$

The total system efficiency evaluates both outputs of a CHP system and compares these to the energy input to the system; it is represented as a percentage. Total system efficiency is effective when comparing a CHP system to a site's separate heat and power generation options [9]; the individual consumption of each piece of plant equipment can be summed together to determine the corresponding energy input required for separate heat and power, and then applied to the above formula.

A possible shortcoming of using this indicator is that it does not differentiate between the values of the power output and the thermal output; instead, it treats power output and thermal output as additive properties with the same relative value. In reality, thermal output and power output are not interchangeable because they cannot be converted easily from one to the other and have different associated generation costs. However, as a method of monitoring the overall performance of a CHP system, this is a suitable energy performance indicator.

4.2 Commentary on indicators for monitoring CHP performance

Total system efficiency is the most suitable indicator for monitoring the performance of the overall CHP system on site. As the CHP system is primarily operated to meet electrical demand, calculation of the effective electric efficiency is worthwhile for monitoring the performance of the CHP as an electrical generator. The information required to obtain these two values is the same; therefore, once total system efficiency is calculated, there is no extra metering required for finding the effective electric efficiency. The only different value required is the efficiency of the technology that would otherwise be used rather than the CHP system to generate heat. This is taken to be the efficiency of the boiler, which should be found through the implementation of the desired energy performance indicator for the boiler system.

Use of these two metrics requires the metering of:

- Fuel supplied to system;
- Electrical power generated;
- Flow rate steam/water produced;
- Temperature of flow and return streams;
- Heat utilised; and
- Heat dumped/wasted.

For the total system efficiency to be calculated accurately, it is necessary to determine the useful electric power output from the system. This value is found by subtracting the parasitic electric losses from the gross electric output of the generator [9]. It may be satisfactory to ignore parasitic losses if they represent a small percentage of the electricity generated; there may also be difficulty in metering these losses.

Ideally, the heat generated by the system is all put to use. However, if this is not the case, it is important to determine the usable heat generated. The useful thermal output is representative of the heat utilised and is approximately equal to the heat generated minus the heat dumped/wasted.

If there is a significant amount of heat being generated by the CHP system but not being utilised, there may be significant energy use associated with 'dumping' heat; this should be included in the energy input to the system to find an accurate value for total system efficiency.

The calculation for effective electric efficiency should only consider the total heat generated and not take into account the heat which is not utilised. As the purpose of this energy performance indicator is to monitor the performance of the CHP system as an electrical generator, inclusion of the heat not utilised would distort the calculated value for effective electric efficiency.

To be considered for a carbon tax rebate, the CHP system must meet the efficiency requirements as laid down in Directive 2004/8/EC.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:052:0050:0060:EN:PDF

Specific guidance is given by the Commission for Regulation of Utilities here:
https://www.cru.ie/wp-content/uploads/2012/07/cer12125.pdf

5 Gas boiler for hot water or steam generation

5.1 Review of indicators for gas boilers or steam generation

5.1.1 Thermal efficiency

Thermal efficiency measures how well a boiler's heat exchanger transfers heat from the combustion process to water or steam. A simple ratio expressed as a percentage, thermal efficiency is basically the input energy in the form of gas or oil or other fuel transferred to the water heating process divided by the output energy in the form of water or steam.

Thermal efficiency's shortcoming as a measure of boiler efficiency is that it only measures the effectiveness of the heat exchanger. Because thermal heat can also be lost through radiation and convection via other boiler components, such as the shell or water column, thermal efficiency is therefore limited as a calculation for measuring boiler efficiency [11].

5.1.2 Combustion efficiency

Combustion efficiency can be used as an energy performance indicator to monitor boiler combustion efficiency. It is a measure of how effectively the heat content of a fuel is transferred into usable heat. The following equation is used to determine combustion efficiency [12]:

$$Eff_{comb.} = \frac{Total\ heat\ released\ in\ combustion - heat\ lost\ in\ stack}{Total\ heat\ released\ in\ combustion}$$

The heat released in combustion is determined by measuring the flow of fuel input to the process and applying a known heating (calorific) value to the fuel. It is necessary to measure the oxygen and carbon dioxide levels in flue gases, the temperature of both combustion air and of flue gases, and the flow rate of gases out of the flue. The heat loss in the flue stack can be calculated based on dry gas loss, moisture loss and humidity loss. Dry gas loss calculation is affected by the weight of gas that leaves the system in the form of unburned fuel. Moisture loss calculation is affected by the weight percentage of the hydrogen and moisture in fuel. Humidity loss calculation is affected by the weight of moisture in the air in unburned fuel [13]. These losses can be determined using known chemical equations for fuel combustion in combination with the measurements previously outlined.

The use of combustion efficiency as an energy performance indicator is limited in its accuracy as it does not account for radiation and convection losses in the process; only the losses through the stack are accounted for using this method. However, the monitoring of flue gases is beneficial for analysing whether the boiler is performing efficiently and for informing decisions to improve boiler efficiency.

The stack temperature and flue gas oxygen or carbon dioxide concentrations are primary indicators of combustion efficiency, as these indicate the heat loss in the stack. Reaching optimum combustion efficiency typically requires pumping excess air into the combustion chamber so that all fuel can be burned. The correct amount of excess air is determined by analysing flue gas oxygen or carbon dioxide concentrations. Inadequate excess air results in unburned combustibles (fuel, soot, smoke, and carbon monoxide), while too much results in heat loss due to the increased flue gas flow, thus lowering the boiler efficiency. A boiler is considered efficient when it has very low levels of unburned fuel and does not require much extra air [14], [11]. The levels of unburned fuel are measured with a smoke pump and associated indicator or smoke number.

Flue gas temperature is an indication of how effectively combustion heat is being transferred to the boiler water. In general, a lower flue gas temperature (a greater difference between the combustion and flue temperatures) indicates better heat transfer and higher overall efficiency. Monitoring flue gas temperatures can be beneficial, as if the temperature rises it is an indication that there is less heat being transferred to the water side of the process; this may indicate the need to clean the heat transfer surfaces on both the fire side (soot) and the water side (scale) [15].

5.1.2.1 Fuel-to-water efficiency

By correcting the deficiencies in thermal efficiency and combustion efficiency calculations, fuel-to-water efficiency attempts to measure the overall efficiency of a boiler's transfer of heat from the combustion process to the water in the boiler. In doing so, it measures the efficiency of the heat exchanger while also accounting for stack, radiation and convection losses through other areas in the boiler plant. Fuel-to-water efficiency is the most suitable energy performance indicator for monitoring a boiler's performance over time.

5.1.2.2 Energy balance method

The energy balance method consists of subtracting the actual stack, radiation, and convection losses, expressed in percentages, from an ideal 100% efficiency in the conversion of heat from fuel provided [11]. The stack losses are determined as outlined in the previous section and require the measurement of fuel input, oxygen and carbon dioxide levels in flue gases, the temperature of both combustion and flue gases, and the flow rate of gases out of the flue.

When in operation, boilers get hot and will, as a result, lose heat to the surrounding environment in the form of both radiation and convection losses. Measurement of the actual loss is complex, tedious, time-consuming and seldom undertaken [16]. Due to the difficulty of accurately measuring radiation and convection losses, they are generally viewed as a constant for a particular boiler [11]. These losses are based on the boiler's surface area that is exposed to the environment.

The use of the energy balance method to determine an energy performance indicator for fuel-to-steam efficiency is flawed in that there are a high number of measurements needed to determine the stack losses for the system, and the radiation and convection loss values are assumed constant based on the difficulty of measurement. The introduction of these fixed values would also introduce a static portion to the indicator, which would not change while the efficiency is being monitored.

5.1.2.3 Input–output method

The input–output method divides the boiler output by the boiler input and then multiplies the result by 100 so that it can be expressed as a percentage. As the two required values are from the beginning and the end of the process, this method accounts for stack, radiation and convection losses; it does not quantify them individually.

$$Eff_{F-S} = \frac{Heat\ generated}{Energy\ input} \times 100$$

For a boiler producing steam, the heat generated is found by measuring the flow rate and the pressure/temperature of the steam produced. If the boiler is producing hot water, it is necessary to measure the flow rate and the flow and return temperatures of the water. The energy input required for the calculation is found by measuring the flow rate of fuel to the boiler. The heating value – higher heating value or lower heating value – of the fuel is then used to express energy input in kWh.

The heating value of a fuel is also known as the calorific value; it represents the amount of heat produced when a unit amount of that fuel is completely combusted [17]. The heating value of a fuel can be categorised as either the higher or the lower heating value.

The higher heating value (also known as gross calorific value or gross energy) of a fuel is defined as the amount of heat released by a unit amount of fuel (initially at 25°C) once it is completely combusted at stoichiometric conditions, the products have returned to a temperature of 25°C, and any water vapour produced has been condensed. Condensing any water vapour produced during determination of the higher heating value means that it includes the heat of vaporisation of the water produced. Stoichiometric conditions mean that there is no oxygen left in the combustion products [17], [18]. The higher heating value is the theoretical total of the energy in the fuel. However, all common fuels contain hydrogen, which burns with oxygen to form water, which passes up the stack as steam. The higher heating value of the fuel includes the energy used in evaporating this water [19].

The lower heating value (also known as net calorific value) of a fuel is defined as the amount of heat released by combusting a unit amount of fuel (initially at 25°C) and returning the temperature of the combustion products to 150°C, which assumes that the latent heat from vaporising the water in the reaction products is not recovered. The lower heating value is essentially the higher value minus the heat of vaporisation for the process [17], [18]. As all fuels form steam which passes through the stack, it is not possible to alter the heat of vaporisation required by the process.

The use of either the higher or the lower heating value is equally applicable for the purpose of determining an energy performance indicator using the input–output method outlined.

5.2 Commentary on indicators for monitoring boiler performance

The input–output method of determining fuel-to-steam efficiency is the most suitable energy performance indicator for the monitoring of boiler performance over time on site. The reasons for the suitability of this indicator are that it accounts for all losses within the system and that it is a simpler method, from a measurement and calculation point of view, to use than the energy balance method outlined previously.

However, it simply indicates the efficiency and does not monitor the factors that influence the value gained. Therefore, it is suitable for the overall monitoring of system performance, but it is not suitable for informing decisions regarding improvement of boiler performance. Monitoring of flue gases would be beneficial for the purpose of understanding how the energy performance indicator is influenced.

6 Conclusion

The following recommendations outline the energy performance indicators that should be established to allow for each of the four systems dealt with in this report to be meaningfully monitored.

For chilled water the coefficient of system performance is the preferred indicator for the **chilled water system**. This divides the useful refrigeration that the chiller carries out by the electrical energy requirement of the system. It is a suitable indicator for monitoring the performance of the entire system. To achieve this indicator, it is necessary to meter the flow rate of the supply or return stream from the main header.

The ideal energy performance indicator for use on the **compressed air system** compares the power consumption of the system to the quantity of compressed air being generated. A calculated value of kWh/Nm^3 would allow for the performance of the system to be monitored.

With **CHP systems**, it is recommended that two indicators be established to monitor performance. Total system efficiency is most suitable for monitoring the performance of the overall system; it compares the total energy input to the sum of the electricity and useful heat generated. Specific guidance is given by the Commission for Regulation of Utilities here: https://www.cru.ie/wp-content/uploads/2012/07/cer12125.pdf

However, the preferred energy performance indicator for the boiler used for **hot water generation** is fuel-to-water efficiency. This should be calculated using the input-output method, which divides the heat output from the boiler by the energy consumption of the boiler.

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