European
Commission

A Study on Energy Efficiency in Enterprises: Energy Audits and Energy Management Systems

Library of typical energy audit recommendations, costs and savings

Energy

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1. Introduction

1.1. Background

. Europe 2020 is the EU's growth strategy that aims to ensure a smart, sustainable and inclusive economy, driven by five interrelated headline targets. These targets address education, employment, poverty and social exclusion, research and development as well as climate change and energy. With regard to the latter, specific targets include achieving 20% of energy supply from renewable sources, a reduction of greenhouse gas emissions of at least 20% as compared to 1990 levels, and an increase of energy efficiency by 20% as compared to a baseline projection. To support the achievement of the latter target on energy efficiency, the Energy Efficiency Directive (EED) came into force on 5 December 2012 and had to be transposed into Member State legislation by 5 June 2014. The Directive is designed to remove barriers and failures in the energy market while establishing a set of binding measures.

Article 8 of the EED gives energy audits and energy management schemes a substantial role to play in improving energy efficiency in the end-use sectors. The EED requires Member States to promote and ensure the use of high quality, cost-effective energy audits and energy management systems to all final customers. This concerns large as well as small- and medium-sized enterprises (SMEs).

Article 8: Energy audits and energy management systems

1. Member States shall promote the availability to all final customers of high-quality energy audits which are cost-effective and are:

   (a) carried out in an independent manner by qualified and/or accredited experts according to qualification criteria; or

   (b) implemented and supervised by independent authorities under national legislation.

   The energy audits referred to in the first subparagraph may be carried out by in-house experts or energy auditors provided that the Member State concerned has put in place a scheme to assure and check their quality, including - if appropriate - an annual random selection of at least a statistically significant percentage of all the energy audits they carry out.

   For the purpose of guaranteeing the high quality of the energy audits and energy management systems, Member States shall establish transparent and non-discriminatory minimum criteria for energy audits based on Annex VI.

   Energy audits shall not include clauses preventing the findings of the audit from being transferred to any qualified/accredited energy service provider, on condition that the customer does not object.

2. Member States shall develop programmes to encourage SMEs to undergo energy audits and the subsequent implementation of the recommendations from these audits.

   On the basis of transparent and non-discriminatory criteria and without prejudice to Union State aid law, Member States may set up support schemes for SMEs, including if they have concluded voluntary agreements, to cover costs of an energy audit and of the implementation of highly cost-effective recommendations from the energy audits, if the proposed measures are implemented.

Member States shall bring to the attention of SMEs, including through their respective representative intermediary organisations, concrete examples of how energy management systems could help their businesses. The Commission shall assist Member States by supporting the exchange of best practices in this domain.

3. Member States shall also develop programmes to raise awareness among households about the benefits of such audits through appropriate advice services.

   Member States shall encourage training programmes for the qualification of energy auditors in order to facilitate sufficient availability of experts.

4. Member States shall ensure that enterprises that are not SMEs are subject to an energy audit carried out in an independent and cost-effective manner by qualified and/or accredited experts or implemented and supervised by independent authorities under national legislation by 5 December 2015 and at least every four years from the date of the previous energy audit.

5. Energy audits shall be considered as fulfilling the requirements of paragraph 4 when they are carried out in an independent manner, on the basis of minimum criteria based on Annex VI, and implemented under voluntary agreements concluded between organisations of stakeholders and an appointed body and supervised by the Member State concerned, or other bodies to which the competent authorities have delegated the responsibility concerned, or by the Commission.

   Access of market participants offering energy services shall be based on transparent and non-discriminatory criteria.

6. Enterprises that are not SMEs and that are implementing an energy or environmental management system - certified by an independent body according to the relevant European or International Standards - shall be exempted from the requirements of paragraph 4, provided that Member States ensure that the management system concerned includes an energy audit on the basis of the minimum criteria based on Annex VI.

7. Energy audits may stand alone or be part of a broader environmental audit. Member States may require that an assessment of the technical and economic feasibility of connection to an existing or planned district heating or cooling network shall be part of the energy audit.

   Without prejudice to Union State aid law, Member States may implement incentive and support schemes for the implementation of recommendations from energy audits and similar measures.

Annex VI: Minimum criteria for energy audits including those carried out as part of energy management systems

The energy audits referred to in Article 8 shall be based on the following guidelines:

(a) be based on up-to-date, measured, traceable operational data on energy consumption and (for electricity) load profiles;

(b) comprise a detailed review of the energy consumption profile of buildings or groups of buildings, industrial operations or installations, including transportation;

(c) build, whenever possible, on life-cycle cost analysis (LCCA) instead of simple payback periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates;

(d) be proportionate and sufficiently representative to permit the drawing of a reliable picture of overall energy performance and the reliable identification of the most significant opportunities for improvement.

Energy audits shall allow detailed and validated calculations for the proposed measures so as to provide clear information on potential savings.

The data used in energy audits shall be storable for historical analysis and tracking performance.

1.2. Aim

Under Article 8(1) of the EED, Member States must promote the availability to all final customers of high quality energy audits which are cost effective and (a) carried out in an independent manner by qualified and/or accredited experts according to qualification criteria; or (b) implemented and supervised by independent authorities under national legislation[1].

This study aims to support the European Commission by providing an overview of current implementation practices, tools and instruments related to Article 8 of the EED within the different Member States. This report, specifically, addresses the development of a library of typical energy audit recommendations, costs and savings. In the sections that follow, this task is split into two principle components:

- The compilation of representative data on the relative cost of energy audits
- The creation of a library structure, within which typical audit recommendations and their projected savings are listed. These represent the most significant energy efficiency opportunities.

1.3. Methodology

The data sources that were used to address the core objectives of this task include:

- Information documented through a literature review:
  The first element in the data collection activity was a structured review of existing documents and literature pertaining to energy audits (typical recommendations and their estimated savings, as well as average costs).

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[1] Guidance note on Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EC, and repealing Directives 2004/8/EC and 2006/32/EC: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013SC0447&from=EN

Within this step, an identification and review of relevant literature, databases and other material (e.g. National Energy Efficiency Action Plans, EED implementation reports, FAQs related to Article 8 of the EED in different Member States, etc.) was carried out. This served as a means to provide a preliminary description of current practice in Member States with regards to energy saving measures and audit costs.

- Results obtained from qualitative interviews:
  The literature review was complemented by information gathered through interviews with experts on a per Member State basis. The interview study aimed to fill information gaps that could not be closed by the literature review, either due to a lack of relevant literature or because it was simply outdated. Furthermore, the interviews served to verify preliminary findings. Interview partners were chosen based on data gaps and do not represent an even or representative split over Member States. The interview partners were either familiar with the implementation of Article 8 or with the improvement of energy efficiency in large organisations and SMEs. They originated from different institutions such as national public bodies, those implementing the requirement of Article 8 at national or regional level, and consulting or research institutions. All interviews were based on semi-structured interview guidelines. A total of 30 interviews were carried for this study, covering 22 Member States.

- Input obtained through stakeholder network engagement activities:
  During the European Sustainable Energy Week 2015 in Brussels (Belgium), our team organised a workshop with an exclusive focus on Article 8 implementation. Several panellists offered their perspectives on Article 8's "state of play", and discussed their "keys to success", as well as engaging in practical discussions to help Member States overcome challenges faced in carrying out specific implementation activities, including the design of certification schemes for energy auditors. A week before the workshop, we also organised an informal session on the same topic during the eceee (the European Council for an Energy Efficient Economy) Summer Study in Toulon (France). Contacts and input from both activities were used to feed into the libraries developed under this task.

- Results from a quantitative survey:
  In parallel with the literature review and the qualitative interviews, an online survey was conducted to improve both the volume and the breadth of perspectives to be addressed in the various study tasks. Topics were covered by high-level and mostly closed-ended questions tailored to the type of respondents targeted. The online survey was sent to enterprises (large and SMEs), energy auditors, public authorities, sector associations and research institutes to gather additional information for the different research questions, including information on energy audit costs. A total of 118 responses was received, the majority of which came from enterprises (46%), followed by auditors (20%) and public authorities (16%). Research institutes (11%) and sector associations (7%) accounted for the remaining responses.

- In-house information from the project team:
  In addition to the research activities, we have used in-house information and energy audit databases maintained by Ricardo Energy & Environment and DNV GL. Both are consulting companies carrying out energy audits, and are therefore a direct source of energy audit costs and typical saving recommendations.

1.4. Terms and definitions

As a prerequisite to the analysis, a set of terms and definitions needs to be established.

1.4.1. Energy audit

An energy audit is a systematic procedure with the purpose of obtaining adequate knowledge of the energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation, or a private or public service, identifying and quantifying cost-effective energy saving opportunities, and reporting the findings.

1.4.2. Energy audit minimum requirements

Annex VI (b) of the EED provides guidelines on energy audits and states that they must be based on up-to-date, measured and traceable operational data on energy consumption and (for electricity) load profiles; comprise a detailed review of the energy consumption profile of buildings or groups of buildings, industrial operations or installations, including transportation; build whenever possible on life-cycle cost analysis (LCCA) instead of simple payback periods (SPP) in order to take account of long-term savings, residual values of long-term investments and discount rates; and be proportionate and sufficiently representative to permit the drawing of a reliable picture of overall energy performance and the reliable identification of the most significant opportunities for improvement. Energy audits shall allow detailed and validated calculations for the proposed measures so as to provide clear information on potential savings. The data used in energy audits shall be storable for historical analysis and tracking performance.

1.4.3. Energy savings

Energy savings means an amount of saved energy determined by measuring and/or estimating consumption, before and after implementation of an energy efficiency improvement measure, whilst ensuring normalisation for external conditions that affect energy consumption.

1.4.4. Energy efficiency improvement

Energy efficiency improvement means an increase in energy efficiency as a result of technological, behavioural and/or economic changes.

1.4.5. Primary energy consumption

Primary energy consumption means the gross inland consumption, excluding non-energy uses.

1.5. Outline of the study

Section 2 provides an overview of typical energy audit costs in different Member States, based on the type of audit being carried out. In section 3 of this report, a library of typical energy saving measures is shown, together with their anticipated savings. An overarching conclusion on the research questions within this task is given in section 4.

2. Typical energy audit costs

The cost of energy audits is highly variable depending on the sector, the size of the facility, the qualifications of the energy auditor and/or auditing firm, the type of audit (buildings, processes or transport or a combination), the accuracy and completeness of information provided by the client, the level of competitiveness in the auditor market and the detail provided by the expert.

Certain sectors (such as the food and drink industry) are highly price-sensitive and this may influence the price of energy auditing services provided. Other sectors (such as the chemical industry) are more concerned about quality and process safety, and therefore may value a more comprehensive (i.e. more detailed and hence more expensive) set of energy audit services.

Large energy audit service providers often need to recover relatively large overhead costs, resulting in higher billing rates, whereas smaller companies or independent energy auditors can offer similar services at a lower cost.

Across Member States, other aspects – such as tax laws, the general cost of living, energy costs, reporting requirements, auditor qualifications, etc. will also vary. For example, an energy audit in Germany, the UK or the Benelux is expected to cost more than an audit in Eastern European countries. Similarly, when the organisation requesting energy audits is a multinational company, the costs of providing energy audits across borders will likely be higher than for single-country organisations. The following sections provide examples of the factors affecting audit costs in a selection of Member States.

2.1. Energy audit costs in Ireland

As stated in the energy audit guidelines of SEAI Ireland (Sustainable Energy Authority of Ireland), audit cost will depend on the scale of the company's operations, and the amount of previous work carried out in understanding energy use. SEAI will define the minimum standards for the audit in line with the requirements of the Directive, and publish a list of registered auditors. However, it is up to individual companies to select an appropriate auditor and to negotiate any fees that apply (SEAI, 2015).

2.2. Energy audit costs in Austria

According to BMWFW Austria (BundesMinisterium für Wissenschaft, Forschung und Wirtschaft), the cost of implementing an energy management system depends on the company and the scope of the system, with a typical cost of around €25,000 per year. This estimated cost includes the establishment of a management system, support by external consultants, certification and internal staff costs. The cost of undertaking an energy audit is estimated at an average of €8,000, but again depends on the size of the company and the thoroughness, depth and scope of the audit (BMWFW, 2015).

2.3. Energy audit costs in Slovakia

According to the Slovak Innovation and Energy Agency SIEA (Slovenská Inovačná a Energetická Agentúra) it is very difficult to determine an average cost for energy audits. Auditors need to work with real energy consumption data and company characteristics, often have to "hunt down" the necessary data, verify obtained data, or even provide special measurements when information is lacking. In an ideal situation (i.e. when all the required information is readily available and correct), the price of an energy audit could be derived from the energy consumption of the company, but in practice it is directly related to the number of hours spent by the auditor. This is often related to the size of the company being audited (SIEA, 2015).

SIEA has identified some good practice examples could lower energy audit costs by up to 30% (SIEA, 2015):

- To audit a hotel with a floor area of 3,200 m², a total of 100 hours was needed (i.e. 0.031 hours/m²). Over one third of this time was needed for site visits and collecting all the required information. There was no information on technical systems readily available, and energy bills did not show individual consumption areas.
- To audit an office building with a floor area of 9,300 m², a total of 116 hours was needed (i.e. 0.012 hour/m²). There were only annual data on energy consumption for the entire building available, so the auditor had to determine the detailed consumption by measuring geometric parameters of the building, and mapping the heating and lighting system, this took over 30% of the audit time.
- To audit an administrative building with a floor area of 7,600 m², a total of 72 hours was needed (i.e. 0.009 hours/m²). This was significantly cheaper than the above examples because complete documentation on previous energy saving projects was available, together with information on the heating and lighting systems. It was therefore not necessary to make a detailed inspection, which could be carried out in less than 10% of the total audit time.

2.4. Energy audit costs in the UK

When looking for an ESOS lead assessor in the UK to perform the energy audit of a company’s offices, with a total floor area of around 5,800 m², price ranges from €5,600 to €42,300 were received (i.e. €0.97-7.92/m²). These striking results show that energy audit providers do not always use the same criteria to determine or estimate the audit price. It could be expected that the audit price of a building would be based on the floor area, but this was definitely not the case for the UK example.

2.5. Energy audit costs in France

In France, it is estimated that about 5,000 companies will have to comply with the energy audit obligation, at a cost between €15,000 and €20,000 (CCI, 2015).

2.6. Energy audit costs in Hungary

The energy audit guidelines of MEKH Hungary (Magyar Energetikai és Közmuszabályozási Hivatal) state that the exact price of energy audits cannot be specified (MEKH, 2015).

2.7. Energy audit costs in different Member States based on the project consortium’s experience

The tables below show cost estimations of energy audits in different EU Member States. These energy audits follow the minimum criteria laid out in Annex VI of the EU EED and any additional criteria imposed by the country legislation transposing Article 8. They should be carried out by accredited or qualified auditors with the necessary education, skills and experience to ensure the quality of the audits.

The energy audit costs shown have been split into the following categories: manufacturing, offices, retail, warehouses, transport fleet and other, in order to allow for a better comparison of prices between different Member States. This split has been made since auditing a manufacturing process is generally more complex and time-consuming than auditing an office for example, which should be reflected by the differences in price.

Obtaining cost data is not an easy task as this information is often commercially sensitive and is therefore not disclosed. In the scope of this project, we are therefore not able to give a complete overview of audit costs in all Member States. For most of the categories mentioned above, the tables show costs for Germany, France, Italy, Denmark, Romania, Sweden, Belgium and the UK. Belgian prices are often expressed on a different basis (i.e. primary energy consumption, occupied area, type of facility), and direct comparison with the other Member States is therefore not always possible. UK prices are also expressed on a different basis (type or complexity of activities), and are therefore collected in a separate table without comparison to the other Member States. Energy audit costs for manufacturing sites are also provided for Czech Republic, Poland, Romania, Spain and Sweden, as a function of the primary energy consumption.

Note that, due to a lack of sufficient available cost data, the prices stated below have no real significant value, as the sample sizes are often not representative for the entire Member State referred to. The costs stated for Germany, France, Italy, Denmark, Romania and Sweden are based on single data. Only for Belgium and the UK do the price ranges indicate average costs available. Therefore, the graphs provided below do not have any statistical significance (as they are often based on only 1 or 2 data points per series) and are merely provided to illustrate the differences between Member States.

2.7.1. Manufacturing

Table 1 shows some typical energy audit costs for manufacturing sites in Germany, France, Italy, Denmark, Romania, Sweden and Belgium. The audit costs depend on the occupied floor area (m²) and on the energy intensity of the organisation. These two parameters regularly go hand in hand: occupied areas up to 15,000 m² could refer to low energy-intensity processes such as assembly. Medium energy-intensity manufacturing processes could include light machinery and are shown by occupied areas of 15,000 to 40,000 m². Occupied areas over 40,000 m² could represent high energy-intensive processes such as chemical processes, heat treatment, furnaces, heavy machinery, etc.

Occupied area (m²) or energy intensity (PJ)	Member State	Energy audit cost (€)
< 2,500 m²	Germany	€ 10,000
< 2,500 m²	France	€ 9,000
< 2,500 m²	Italy	€ 8,000 - € 9,000
< 2,500 m²	Denmark	€ 8,000
< 2,500 m²	Romania	€ 9,000
< 2,500 m²	Sweden	€ 9,000
2,500-7,000 m²	Germany	€ 12,000
2,500-7,000 m²	France	€ 10,000 - € 11,000
2,500-7,000 m²	Italy	€ 10,000
2,500-7,000 m²	Denmark	€ 10,000
2,500-7,000 m²	Romania	€17,000 - 18,000
2,500-7,000 m²	Sweden	€ 11,000
7,000-15,000 m²	Germany	€ 14,000
7,000-15,000 m²	France	€ 13,000 - € 14,000
7,000-15,000 m²	Italy	€ 12,000 - € 13,000
7,000-15,000 m²	Denmark	€ 15,000
7,000-15,000 m²	Romania	€ 21,000 - € 22,000
7,000-15,000 m²	Sweden	€ 16,000

15,000-40,000 m²	Germany	€ 18,000
15,000-40,000 m²	France	€ 17,000
15,000-40,000 m²	Italy	€ 15,000 - € 16,000
15,000-40,000 m²	Denmark	€ 25,000
15,000-40,000 m²	Romania	€ 22,000 - € 23,000
15,000-40,000 m²	Sweden	€ 27,000
> 40,000 m²	Germany	€ 23,000
> 40,000 m²	France	€ 24,000 - € 25,000
> 40,000 m²	Italy	€ 22,000 - € 23,000
> 40,000 m²	Denmark	€ 29,000
> 40,000 m²	Romania	€ 25,000 - € 27,000
> 40,000 m²	Sweden	€ 32,000
< 0.1 PJ primary energy consumption	Belgium	€ 7,500 - € 10,000
0.1-0.5 PJ primary energy consumption	Belgium	€ 10,000 - € 20,000
0.5-1 PJ primary energy consumption	Belgium	€ 20,000 - € 30,000
> 1 PJ primary energy consumption	Belgium	€ 30,000 - € 100,000
0.015 PJ primary energy consumption	Czech Republic	€ 6,660
0.023 PJ primary energy consumption	Czech Republic	€ 5,550
0.063 PJ primary energy consumption	Poland	€ 5,000
0.021 PJ primary energy consumption	Romania	€ 15,000
0.017 PJ primary energy consumption	Spain	€ 18,000
0.019 PJ primary energy consumption	Spain	€ 18,000
0.022 PJ primary energy consumption	Spain	€ 18,000
0.035 PJ primary energy consumption	Sweden	€ 8,000

Table 1. Energy audit costs for manufacturing

Figure 1 illustrates the differences in energy audit costs for manufacturing sites compared to the total occupied area (€/m²). As a general trend, it can be seen that costs decrease with increasing area. This implies that larger manufacturing sites do not necessarily require an audit effort that is proportionate to the size or the energy intensity of the company. This is also supported by Figure 2, which shows a decreasing trend in specific energy audit cost depending on the primary energy use of a site (€/PJ). Processes in large energy-intensive companies are often similar, and can therefore be subjected to a sampling approach: auditors can choose a representative sample of processes to be audited, and then transfer the audit results to the comparable processes. Moreover, energy-intensive manufacturing sites often include a limited amount of large energy consuming equipment. In these cases auditing one big installation typically takes less time than auditing several smaller installations. The total cost of the energy audit will of course be higher than for smaller sites but, when expressed per unit of occupied area or energy consumption, costs will generally be lower.

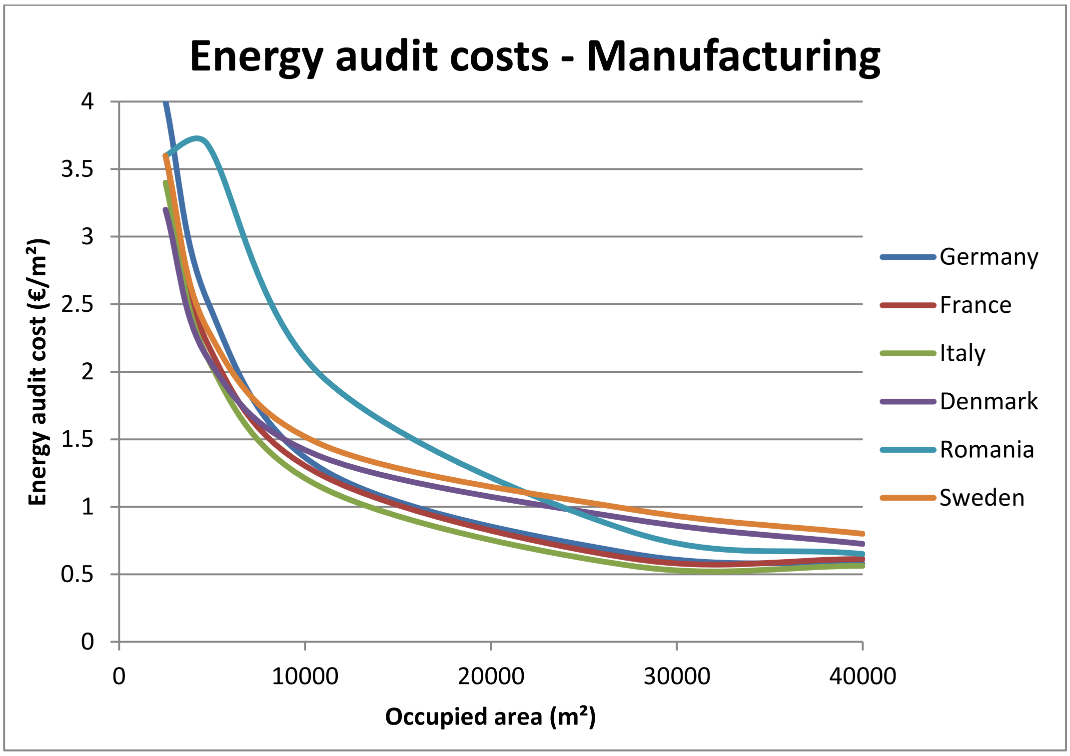

Figure 1. Energy audit costs for manufacturing sites, expressed per unit of occupied area (€/m²)

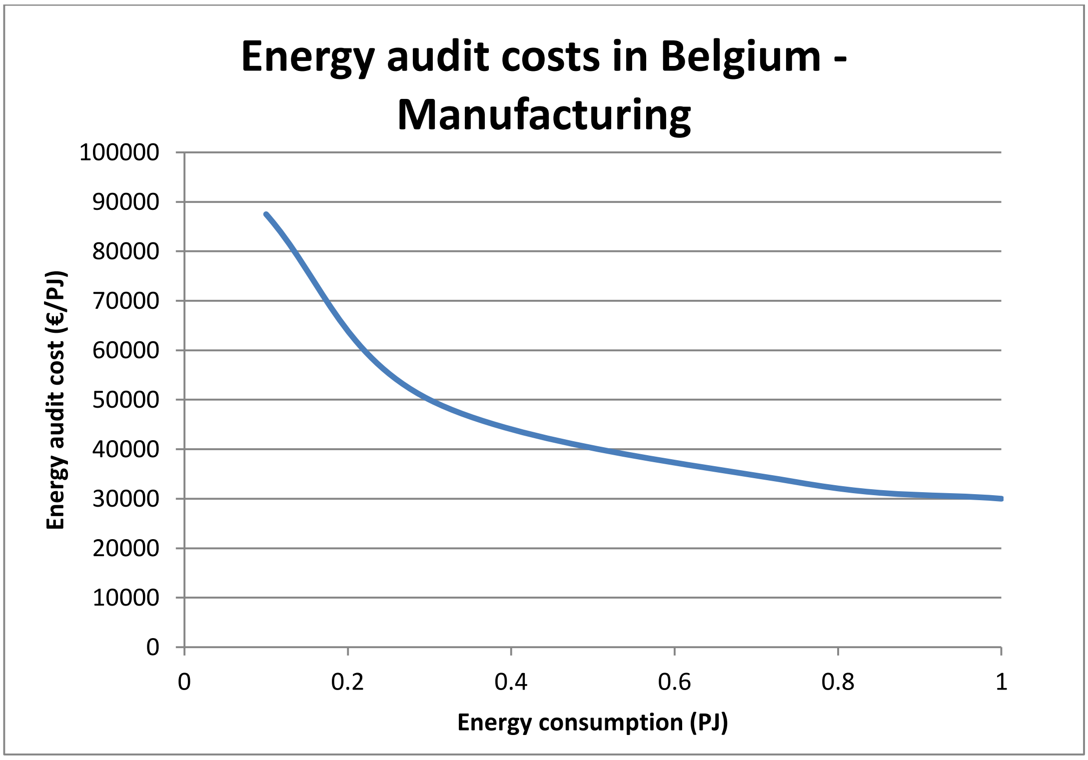

Figure 2. Energy audit costs in Belgium for manufacturing sites, expressed in function of the primary energy consumption (€/PJ)

Figure 1 also illustrates the differences in energy audit costs between selected Member States. Prices are lowest in Italy, Germany and France, and higher in Romania, Denmark and Sweden. The reasons behind the higher prices in Romania are unclear, as we anticipated audit costs to be lower in Eastern European countries, but in the example identified the opposite is true (it should be noted that this is a snapshot and not a general overview of all audit costs in Romania). One explanation could be the fact that the energy audit market in Romania is less mature than in the other Member States, resulting in higher prices. This statement is also supported by evidence shown in the Task 4 report, where it is stated that Romania has a lack of auditors, which could explain the higher audit costs. A lack of auditors was also shown for Denmark.

The energy audit costs as a function of the primary energy use in Spain are even higher than those in Romania and Scandinavia, as shown in the last six rows of Table 1. Average prices vary from €940,000 per PJ primary energy consumption in Spain, to €715,000/PJ in Romania, €343,000/PJ in Czech Republic, €229,000/PJ in Sweden, up to €100,000/PJ in Belgium and €80,000/PJ in Poland.

2.7.2. Offices

Table 2 shows some typical energy audit costs for offices in Germany, France, Italy, Denmark, Romania, Sweden and Belgium. The audit costs depend on the occupied floor area (m²).

Occupied area (m²)	Member State	Energy audit cost (€)
< 7,000	Germany	€ 10,000
< 7,000	France	€ 9,000
< 7,000	Italy	€ 8,000-€ 9,000
< 7,000	Denmark	€ 8,000
< 7,000	Romania	€ 10,000-€ 11,000
< 7,000	Sweden	€ 9,000
> 7,000	Germany	€ 14,000
> 7,000	France	€ 12,000
> 7,000	Italy	€ 11,000-€ 12,000
> 7,000	Denmark	€ 10,000
> 7,000	Romania	€ 13,000
> 7,000	Sweden	€ 11,000
< 500	Belgium	€ 2,000-€ 3,000
500-5,000	Belgium	€ 5,000-€ 7,000
5,000-50,000	Belgium	€ 25,000-€ 30,000
50,000-150,000	Belgium	€ 50,000-€ 60,000

Table 2. Energy audit costs for offices

Figure 3 illustrates the differences in energy audit costs for offices between Member States. Belgium shows the lowest costs, especially for smaller floor areas. The cheaper prices in Belgium could be explained by the fact that the energy auditors market is very mature, with high levels of competition and many small companies offering audits at lower prices than bigger auditing firms. Denmark, Sweden, Italy and France show very similar prices, whereas Germany and Romania show slightly higher costs to audit offices. Romania – as for manufacturing sites – stands out, whereas Germany is also more expensive for auditing offices compared to manufacturing sites.

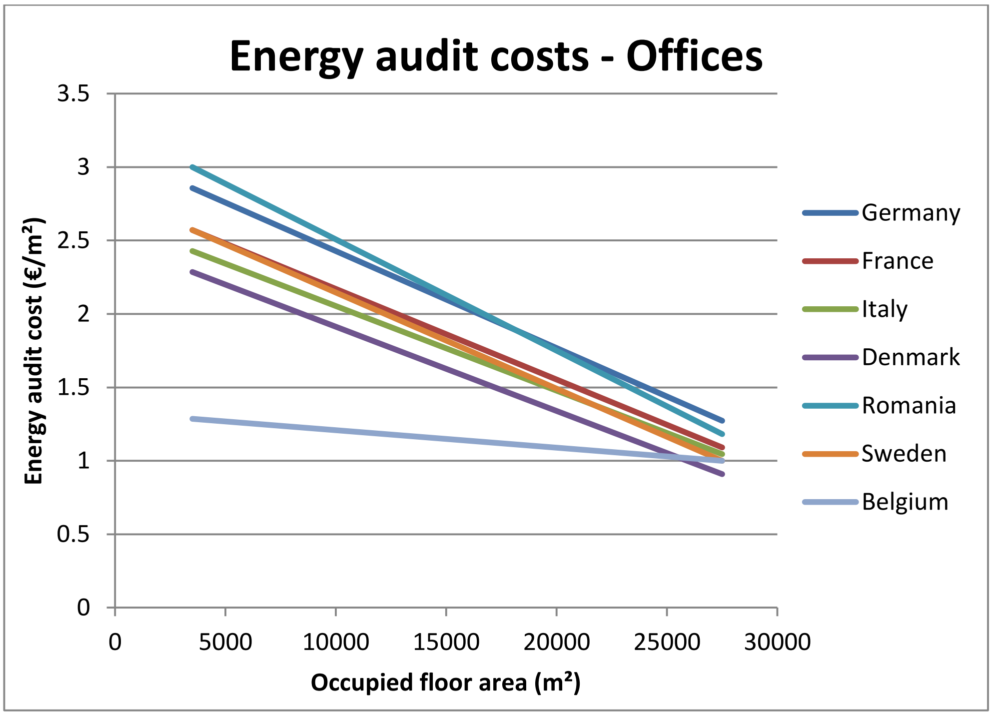

Figure 3. Energy audit costs for offices, expressed per unit of occupied floor area (€/m²)

Figure 4 shows some greater detail on energy audit costs for offices in Belgium. For smaller offices, the costs per unit of occupied floor area are rather high (although still cheaper compared to the other Member States in Figure 3), but these specific audit costs rapidly decrease with an increasing floor area. As for manufacturing, it can be concluded that energy audit efforts for offices are not proportional to the floor area that needs to be audited, since big offices often show the same level of cost as small offices but on larger scale: auditing the lighting system in a small office takes the same amount of time as auditing the lighting system in a large office.

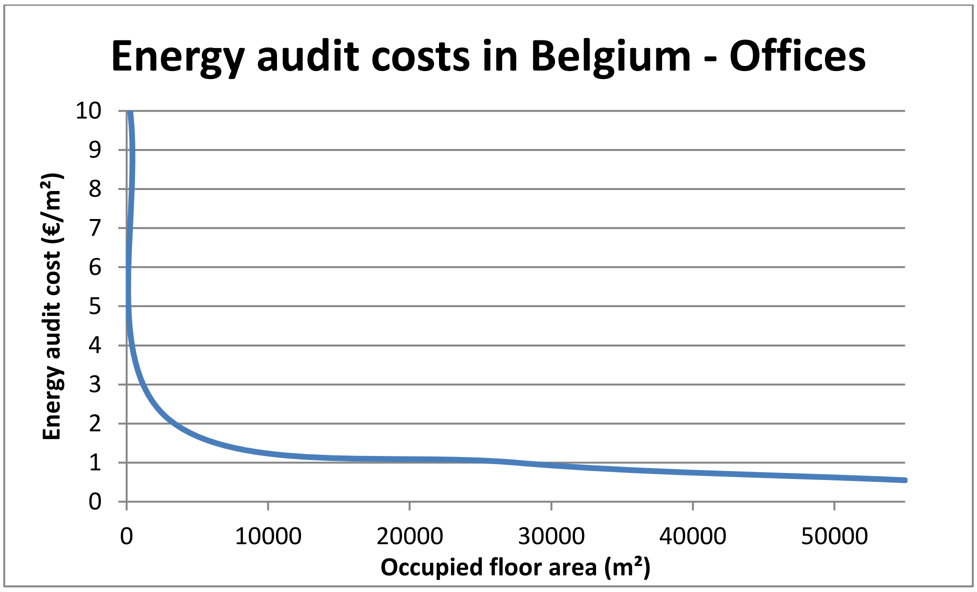

Figure 4. Energy audit costs in Belgium for offices, expressed per unit of occupied floor area (€/m²)

2.7.3. Retail

Table 3 shows some typical energy audit costs for retail companies in Germany, France, Italy, Denmark, Romania and Sweden. No detailed information on prices as a function of occupied floor area was available, so no conclusions can be drawn regarding this point.

Occupied area (m²)	Member State	Energy audit cost (€)
< 6,000	Germany	€ 10,000
< 6,000	France	€ 9,000
< 6,000	Italy	€ 8,000-€ 9,000
< 6,000	Denmark	€ 8,000
< 6,000	Romania	€ 5,000-€ 6,000
< 6,000	Sweden	€ 9,000

Table 3. Energy audit costs for retail

For energy audits of retail companies, Romania shows a significantly lower cost compared to the other Member States (in contrast to the audit costs for manufacturing companies and offices). Again, it is difficult to explain why there is such a big difference, and the price stated might not be representative for the entire country. The other Member States show comparable prices for the audits, ranging from €8,000 to €10,000.

2.7.4. Warehouses

Table 4 shows some typical energy audit costs for warehouses in Germany, France, Italy, Denmark, Romania, Sweden and Belgium. The cheapest audit can be found in Denmark, followed by Belgium (with an average price of €8,250 for an occupied floor area between 2,500 and 7,500 m²) and Italy. Sweden and France are slightly more expensive, followed by Romania and Germany. These audit costs follow the trend for auditing offices when comparing the different Member States.

Occupied area (m²)	Member State	Energy audit cost (€)
2,500-7,500	Germany	€ 14,000
2,500-7,500	France	€ 9,000
2,500-7,500	Italy	€ 8,000-€ 9,000
2,500-7,500	Denmark	€ 8,000
2,500-7,500	Romania	€ 10,000-€ 11,000
2,500-7,500	Sweden	€ 9,000
< 500 (ambient storage)	Belgium	€ 2,000
< 500 (cold storage)	Belgium	€ 3,000
500-5,000 (ambient storage)	Belgium	€ 4,000
500-5,000 (cold storage)	Belgium	€ 6,000
5,000-50,000 (ambient storage)	Belgium	€ 10,000
5,000-50,000 (cold storage)	Belgium	€ 13,000
50,000-150,000 (ambient storage)	Belgium	€ 20,000
50,000-150,000 (cold storage)	Belgium	€ 25,000

Table 4. Energy audit costs for warehouses

Figure 5 illustrates some more detailed energy audit cost ranges for warehouses as a function of the total occupied floor area, differentiating between ambient and cold storage. For cold storage, the costs are slightly higher. As for the previous audit costs, a decrease in specific price can also be seen for warehouses with increasing floor area.

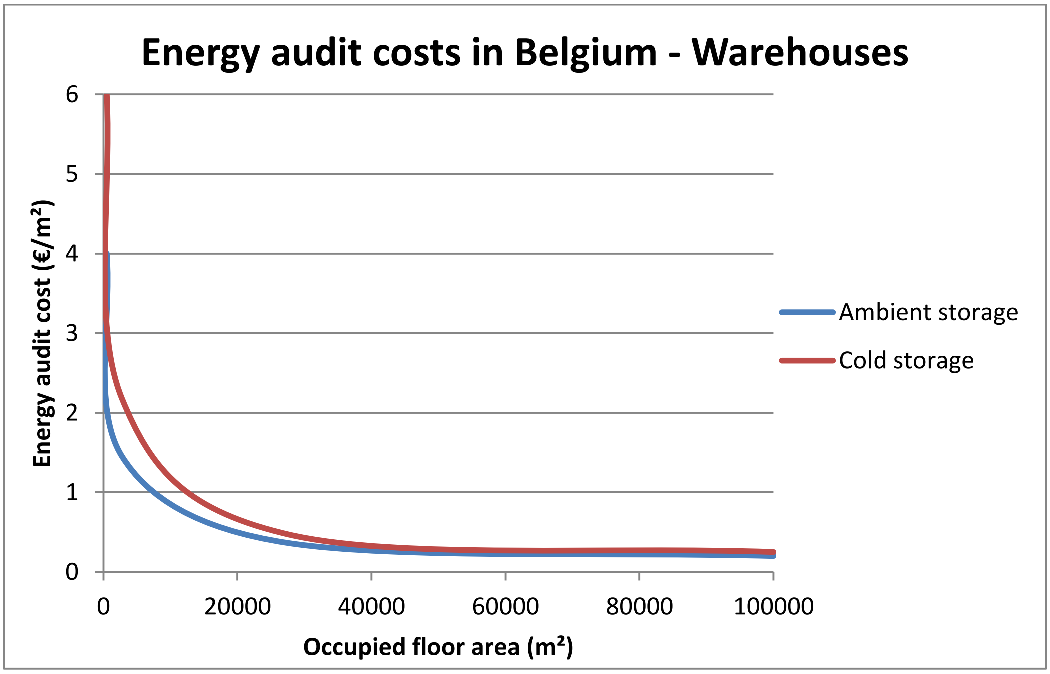

Figure 5. Energy audit costs in Belgium for warehouses

2.7.5. Transport fleets

Table 5 shows some typical energy audit costs for transport fleets in Germany, France, Italy, Denmark, Romania and Sweden. Audit costs depend on the complexity of the fleet: smaller, less complex fleets typically have less than 50 company cars, grey fleet, light commercial vehicles, etc., whereas larger more complex fleets exceed this number.

Complexity of activities	Member State	Energy audit cost (€)
Small, less complex fleet	Germany	€ 3,000
Small, less complex fleet	France	€ 3,000
Small, less complex fleet	Italy	€ 3,000-€ 4,000
Small, less complex fleet	Denmark	€ 5,000
Small, less complex fleet	Romania	€ 5,000
Small, less complex fleet	Sweden	€ 6,000
Large, more complex fleet	Germany	€ 5,000
Large, more complex fleet	France	€ 5,000-€ 6,000
Large, more complex fleet	Italy	€ 5,000-€ 6,000
Large, more complex fleet	Denmark	€ 6,000
Large, more complex fleet	Romania	€ 6,000
Large, more complex fleet	Sweden	€ 7,000

Table 5. Energy audit costs for transport fleets

The cheapest audits for smaller fleets can be found in Germany and France, followed by Italy. Denmark and Romania are slightly more expensive, followed by Sweden. For more complex fleets, Germany is the cheapest, followed by France and Italy, whereas Denmark, Romania and Sweden are the most expensive.

2.7.6. Other

Table 6 provides some additional average energy audit costs, mainly in the UK and one in the Czech Republic. Since no further details on occupied area or energy consumption are available, it is difficult to compare these audit costs and draw any relevant conclusions. Therefore, these audit costs were not included in the previous tables.

Type of site/operation	Energy intensity/complexity of activities	Member State	Energy audit cost (€)
Manufacturing	Large car manufacturer (multiple sites, including transport audit)	UK	€ 8,000-€ 11,000
	Tyre manufacturing	Czech Republic	€ 5,500-€ 7,000
	Other manufacturing	UK	€ 2,500-€ 5,000
Offices	Call centre	UK	€ 1,700-€ 3,500
	Logistics company offices	UK	€ 1,900-€ 2,700
	Other offices	UK	€ 1,600-€ 2,300
Retail	Grocery store	UK	€ 1,400-€ 2,700
	Large bakery	UK	€ 4,000-€ 5,500
	Bank	UK	€ 800-€ 1,400
	Shopping centre	UK	€ 3,400-€ 4,800
	Other retail	UK	€ 1,400-€ 1,900
Miscellaneous	Data centre	UK	€ 3,400-€ 5,500
	Airport (12,000 m²)	UK	€ 4,000-€ 7,000
	Housing developer	UK	€ 1,400-€ 1,900
	Large sporting ground	UK	€ 4,000-€ 5,500
	Sporting stadium	UK	€ 2,000-€ 3,500

Table 6. Energy audit costs for different types of sites or operations

2.8. Survey results

The online survey was sent to 785 unique contacts and resulted in 118 responses in total (a 15% response rate). In response to the question on whether the organisation has undertaken an energy audit within the last four years, only 32 out of the 118 respondents answered: 10 of them gave a negative answer, whereas the other 22 indicated that they had undertaken an audit (13 of them in 2015). The main focus of these audits was either production lines or buildings and, to a lesser extent, on transport. When asked about the total cost range of the energy audits, only 19 respondents (three SMEs and 16 large enterprises) answered: three of them (all SMEs) indicated a cost range below €5,000, four of them between €5,000 and €10,000, three of them between €10,000 and €20,000, two of them between €20,000 and €30,000 and six of them (the majority) over €30,000.

These survey results show higher average audit costs than the data provided above. However, due to the limited amount of available data, it is not possible to draw significant conclusions from this observation.

3. Energy saving measures

3.1. Library of typical energy saving measures

This section sets out a library of typical saving measures for the most significant opportunities for improvement of energy efficiency. Estimates of average energy savings and related costs are also provided (where available). The library contains a list of typical recommendations representing the energy saving opportunities with the highest potential in different sectors. Recommendations are not organised by Member State, as most sectors are present in most countries.

The library is provided as a separate excel file, which presents a list of common energy efficiency measures recommended by energy audits. It classifies measures into the following broad categories: building envelope, HVAC (heating, ventilation and air conditioning), lighting, compressed air, electric motors/pumps/fans/drives, energy management, process cooling and heating, general maintenance, waste heat recovery, automation, waste reduction, heat and steam generation, and other measures.

Focus is put on cross-sector measures, and the library does not include process-specific measures for specific sectors. For industry, a detailed overview of sector-specific energy saving measures can be found in the research papers that have been recently published by PB | WSP and DNV GL for the UK Department of Energy and Climate Change and the Department for Business and Skills (2015) for the iron and steel, pulp and paper, food and drink, chemical, oil refining, glass, ceramic and cement industries.

The choice of measures classification is in line with different research papers, such as Mai et al. (2014), Fleiter et al. (2012) and Köwener et al. (2014).

In 2008, a programme was established in Germany to provide grants for energy audits in SMEs. Fleiter et al. (2012) provides an overview of the types of energy efficiency measures that have been proposed and/or conducted since: heating and hot water, process heat, compressed air, electric motors and drives, ventilation and air conditioning, lighting, building insulation, waste heat recovery, process technology, ICT, cooling (for processes), energy management, behaviour, and other measures. Mai et al. (2014) further evaluated these measures, and found that most measures in initial energy audits were proposed for lighting, heating and hot water, building insulation, ICT and organisational measures (behaviour and energy management) – the so-called “low-hanging fruit” - whereas more advanced audits focussed on process heat, process technology, cogeneration, motors, heat recovery, refrigeration and renewable energy.

In Learning Energy Efficiency Networks (LEEN), 10 to 15 regionally based companies from different sectors share their energy efficiency experiences in moderated meetings. The first network was established in Switzerland in 1987. Currently, 360 companies (in Switzerland, Germany and Austria) participate in the publicly funded 30 pilot networks. These pilot networks have resulted in the identification of approximately 3,600 profitable energy saving measures, corresponding to an energy saving potential of over 1,200 GWh and a CO_2 emissions reduction of nearly 500,000 tonnes annually. Köwener et al. (2014) have analysed these measures. Measures were classified into 10 different technology areas: ventilation, lighting, compressed air, electrical devices, air conditioning, process cooling, process heating, space heating, change of energy carrier (replacement of electricity by fuels for CHP, or replacement of fossil fuels by renewables), and other measures. On average, the most profitable measures were realised in the areas of compressed air and electrical devices. The average internal rate of return of lighting measures seemed to be rather low, but predictable: investing in lighting improvements can hence be seen as low-risk.

The library also presents average energy savings associated with each measure as well as the source of the savings values. These savings are generally presented as a percentage of the equipment's total energy consumption rather than specific units of energy (such as kWh). This makes the content applicable to a wider range of organisation types and sizes, and independent of the equipment's size and energy use.

Where available, approximate costs of implementing the saving measures are also provided. Since these costs are highly dependent on the size and type of organisation, it is often not possible to provide this information, explaining the many gaps in the library.

Not all measures presented will be cost effective (or even applicable) at all sites. It is important to take into account each site's specific needs when considering what measures to implement. Different organisations may have different goals, different plant layouts and different energy prices, and the recommendations of the audit should take these into account. For example, some organisations may only be interested in immediate cost savings and short payback periods, whereas other organisations may be looking to reduce their carbon footprint and long-term energy consumption. Available capital for energy efficiency projects will also play a substantial role in deciding which measures to implement.

For each saving measure, the sector to which it applies has been indicated. The sector definitions applied include offices, logistics, laboratories, production, warehouses and all/any. We have chosen to follow this sector split instead of the generally used Eurostat categories of the European Commission, since energy audit recommendations are typically more cross-cutting.

The references used to develop the library include:

1. California Public Utilities Commission, Database for Energy Efficiency Resources, *available online via http://www.deeresources.com/,* 2011.
2. Carbon Trust, Energy Survey Guide, *Energy surveys: A practical guide to identifying energy saving opportunities, September* 2011.
3. DNV GL, *Energy Savings Identification Tool 2.0,* 2012.
4. US Department of Energy, Energy Efficiency and Renewable Energy – Federal Energy Management Programme, *Boiler Upgrades and Decentralising Steam Systems Save Water and Energy at Naval Air Station Oceana, EERE Information Centre, available online via http://www1.eere.energy.gov/femp/pdfs/oceana_water_cs.pdf, December* 2011.
5. Ernest Orlando Lawrence Berkeley National Laboratory, Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry, *An ENERGY STAR Guide for Energy and Plant Managers, Ernst Worrell, Christina Galitsky, Eric Masanet and Wina Graus, Sponsored by the US Environmental Protection Agency, LBNL-57335-Revision, March* 2008.
6. Ernest Orlando Lawrence Berkeley National Laboratory, Energy Efficiency Improvement and Cost Saving Opportunities for the US Iron and Steel Industry, *An ENERGY STAR Guide for Energy and Plant Managers, Ernst Worrell, Paul Blinde, Maarten Neelis, Eliane Blomen and Eric Masanet, Environmental Energy Technologies Division, Sponsored by the US Environmental Protection Agency, LBNL-4779E, October* 2010.
7. US Department of Energy, Energy Efficiency and Renewable Energy – Federal Energy Management Programme, *Fume Hood Sash Stickers Increases*

Laboratory Safety and Efficiency at Minimal Cost: Success at two University of California Campuses, EERE Information Centre, available online via http://energy.gov/sites/prod/files/2013/10/f3/sash_stickers_cs.pdf, March 2012.

8. Ernest Orlando Lawrence Berkeley National Laboratory, Energy Efficiency Improvement and Cost Saving Opportunities for the Pharmaceutical Industry, *An ENERGY STAR Guide for Energy and Plant Managers, Christina Galitsky, Sheng-Chieh Chang, Ernst Worrell and Eric Masanet, Environmental Energy Technologies Division, Sponsored by the US Environmental Protection Agency, LBNL-57260-Revision, March* 2008.
9. UK DECC and BIS, Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050, *prepared by Parsons Brinckerhoff | WSP and DNV GL for the UK Department of Energy and Climate Change and for the UK Department for Business, Innovation and Skills, 25 March* 2015.
10. DNV GL, Compressed Air – Energy Saving Measures Checklist, 2014.
11. European Commission, Reference Document on Best Available Techniques for Energy Efficiency, February 2009.
12. European Commission, Reference Document on Best Available Techniques in the Ceramic Manufacturing Industry, August 2007.
13. Fleiter Tobias, Gruber Edelgard, Eichhammer Wolfgang and Worrell Ernst, The German energy audit programme for firms: A cost-effective way to improve energy efficiency?, *Energy Efficiency, 5, pp. 447-469,* 2012.
14. Köwener Dirk, Nabitz Lisa, Mielicke Ursula and Idrissova Farikha, Learning Energy Efficiency Networks for companies: Saving potentials, realization and dissemination, *eceee Industrial Sumer Study proceedings, No.* 1-065-14, pp. 91-100, 2014.

Savings opportunities identified in an energy audit will vary greatly depending on:

- The age of the buildings, the process equipment, and the main systems
- The date of the last energy audit or commissioning
- The total energy consumption

The library should therefore be considered a broad guide and not a statement on guaranteed savings.

3.2. Building envelope

The building envelope is the outside shell of a building. It includes external walls, roof and floor as well as the doors and windows. Each one influences the thermal characteristics of the building. There are many dependent parameters that should be considered when assessing the efficiency of the building design (DNV GL, 2012):

- Climate zone: Consider if the main energy consumer is heating or cooling load (often depends on the season)
- Space type: Office, factory/production space, unoccupied, space with critical indoor climate specifications, etc.
- Differentiate between conditioned spaces, semi-heated spaces, and unconditioned spaces
- Building materials

- Building age: Knowledge of building codes in place at the time of the construction of the building will give an indication of the building's construction, which can be used for estimating insulation levels and give an overall indication of the quality of the envelope

In general, the quality of the building envelope can be assessed by infrared imaging (looking for thermal leakages, thermal bridges, and radiation of heat) and leak detection (looking for air drafts, convection of heat). Energy efficiency improvements are often possible in retrofit situations and for new buildings (DNV GL, 2012).

Typical energy saving measures found in the recommendations of energy audits regarding the building envelope include (amongst others):

- **Improved exterior wall and roof insulation**: Increasing a building's insulation will reduce thermal losses. The saving potential ranges between 2 and 40% of the HVAC energy use. This large range is due to differences in the starting and end point of the insulation levels. Several simple calculation tools are available online to help determine savings potential.
- **New energy efficient windows and skylights**: Older windows are often poorly sealed, have low insulation values and poor solar heat gain coefficients. Replacing the entire window, including the frame, and properly sealing around the window frame can drastically reduce infiltration/exfiltration and reduce energy used to heat, cool and ventilate the building. In most cases, replacing windows can be expected to achieve between 4 and 20% savings on HVAC energy use, or even up to 30% in extreme cases.
- **Improved use of windows for heat load/gain**: Windows oriented towards the sun will allow solar heat gain when the sun is shining due to the greenhouse effect. Selective use of this heat gain will yield a reduced heat load in the winter and a reduced heat gain in the summer. Controlling the heat gain can be done by means of permanent shades or built in filters (depending on the angle of the sunshine in each season), or through the use of automatic sunshades. Retrofitting existing windows with energy saving window films may give (heating and cooling) energy savings of about 5% of the HVAC energy use, but this may be as high as 10% in southern climate zones.
- **Reduced air infiltration by sealing**: Air infiltration is the uncontrolled movement of air into and out of a building which is not for the specific and planned purpose of taking out or bringing in fresh air. Envelope leakage has a big impact on the energy use of a building. The major sources of unintended air infiltration are around poorly sealed windows, doors, and poorly constructed building curtain walls (non-load bearing walls to keep the weather out). Typical savings can be up to 30% of the HVAC energy use.
- **Replacing doors and adjusting seals**: Older doors are often not sealed properly and may be poorly insulated. Sometimes adjusting doors and improving the sealing can be enough to reduce infiltration/exfiltration significantly. Estimated savings potential are 0.5 to 5% of the HVAC energy use.
- **Improved roof reflection**: Increasing roof reflectivity can drastically reduce cooling load in warm climates. Dark roofs are heated by the summer sun and thus raise the summertime cooling demand on buildings. For highly absorptive roofs, the difference between the surface and ambient air temperature may be as high as 50°C, while for less absorptive roofs, such as white coatings, the difference is only about 10°C. Savings depend on the climate and the amount of roof insulation. A reflective roof may also lead to a higher heating energy use and reflective roofs are not recommended for cold to moderate climates

where there is no need to cool the buildings. Savings opportunities depend to a great extent on climate.

- **Door closers and powered door operators**: Spring-type door closers will prevent loss of conditioned air from exterior doors left open. Powered door operators may be manual operation based or motion based. The saving potential ranges from 0.1 to 0.5% of the HVAC energy use.
- **Dock-to-truck seals**: The gap between the vehicle and dock is a major path of air leakage. This greatly increases heating requirements. Also, when loading to and from refrigerated trucks and spaces, the air leakage radically increases refrigeration cost. Installing or improving dock-to-truck seals results in savings from 0.5 to 5% of the HVAC energy use.

CASE STUDIES

The UK Department of Energy and Climate Change (DECC) installed occupancy controls in meeting rooms and enclosed offices. The installed sensors will only run the room air-conditioning and lighting when it is occupied, and only within the building's core occupancy hours. These controls avoid wasting energy on empty rooms. The investment cost of €65,000 reduced the CO_2 emissions by 49 tonnes/year. Annual cost savings of €12,000 resulted in a payback period of 5.4 years (DECC, 2012).

Hospitals and other healthcare facilities account for a significant amount of energy use and emissions, because they are open 24 hours a day and have extra commitments on air filtration and circulation, air cooling and waste management. At the Gundersen Lutheran hospital in the US, the following energy saving measures (with their associated costs and payback periods) were identified and implemented (DoE, 2011):

- Chiller tower optimisation: €78,000 investment cost - €57,000 annual savings – 1.4 years payback

- Zone scheduling (exhaust fans and air handlers): €68,000 investment cost - €80,000 annual savings – 0.8 years payback

- Condenser water acid free: €15,000 investment cost - €23,000 annual savings – 0.7 years payback

- Reducing station for HP boilers, boiler economisers, new boiler controls, VFD drives and auto blow-down: €251,000 investment cost - €61,000 annual savings – 4.1 years payback

- Steam traps: €203,000 investment cost - €37,000 annual savings – 5.5 years payback

- Energy efficient lighting system: €1,423,000 investment cost - €233,000 annual savings – 6.1 years payback

- Automatic turn-off of computers: €115,000 investment cost - €34,000 annual savings – 3.3 years payback

- Removable insulation on fittings, valves, unions, etc.: €209,000 investment cost - €77,000 annual savings – 2.7 years payback

- New chiller: €220,000 investment cost - €62,000 annual savings – 3.6 years payback

3.3. HVAC (heating, ventilation and air conditioning)

HVAC systems are responsible for heating and cooling a building as well as providing adequate ventilation. A HVAC system's design can vary greatly. Among the possible choices are (DNV GL, 2012):

- Single-zone or multi-zone systems (packaged or split systems)
- Constant volume or variable air volume (VAV) systems (generally utilising chillers and/or boilers)
- Reheat or induction systems
- Single-, dual- and triple-duct systems (single-duct is most common, generally also uses chillers and/or boilers)

Cooling systems reject heat through a refrigeration cycle in order to cool a building’s space while most heating applications use combustion to heat conditioned space. Exceptions are heat pumps or resistance heaters, which both use electricity as the “fuel”. A heat pump uses electricity to run the refrigeration cycle run in reverse (essentially pulling heat from the environment instead of rejecting heat) while a resistance heater uses electricity directly to produce heat (DNV GL, 2012). Savings opportunities include:

- **Turn off ventilation system when possible/minimise ventilation rate and outdoor air**: Using a sensor or time based control will limit the amount of outside air that needs to be conditioned. Savings are highly variable depending on control type and can be anywhere from 1 to 95% of HVAC energy use.
- **Exhaust air heat recovery**: Recover heat from air that must be expelled from a building. There are many kinds of heat exchangers for this application and their efficiencies range from 45 to 90%.
- **Limit air leaks around HVAC units and ducts**: On average, 10 to 25% of conditioned air is lost through leaks in the duct system. Leakage increases power consumption of the HVAC unit in two ways: producing more conditioned air and increasing fan power.
- **Use high efficiency motors**: Replace old or inefficient motors with high efficiency motors for a 2-8% reduction in energy consumption.
- **Use multi-speed or variable speed fan motors**: Fans are often sized to accommodate maximum heating or cooling loads, however these only account for a fraction of the system’s operating hours. Options include a multi-speed fan or a variable speed drive. The VSD is more efficient but also more expensive. Multi-speed fans can produce significant savings for less upfront cost. Reheat energy use can be decreased by 30 to 60% when compared to a constant volume system. Fan energy can also be reduced by 50 to 80%.
- **Improve thermostat operation and control**: Introducing a “dead band” thermostat can reduce HVAC energy consumption by between 1 and 10%. This means that heating and cooling is turned off whenever space temperature is within a given temperature range (normally a few degrees). Implementing a setback temperature for unoccupied spaces can also save up to 20% of cooling energy.
- **Chiller controls**: Installing advanced chiller controls can save anywhere from 1 to 20% of chiller consumption. Control options include selective chiller control (chiller staging), outdoor air enthalpy controls, timed/scheduled plant operation, and optimising chiller water discharge temperature.
- **Improve chiller heat rejection**: Cleaning condenser water tubes, reducing bleed rate and installing multi-speed or VSD fans on cooling towers can all

increase heat rejection efficiency and reduce chiller plan energy consumption by a few percent.

- **Replace old compressors with more efficient modern compressors**: Replacing chiller compressors can reduce energy consumption by 10 to 35% and can pay for itself within a year. This is normally less expensive than replacing the entire chiller.
- **Thermal storage**: Installing a thermal storage tank means that chilled water can be produced early in the morning when ambient temperatures are lower and therefore use less energy. If a site has time of use billing, it also allows chilled water to be produced with lower cost electricity.
- **Install a water side economiser for free cooling**: A cooling tower can pre-cool water before the chiller or the water can be used directly for cooling when the ambient temperature is sufficiently low. Savings depend on the annual hours where the outdoor temperature is sufficiently low, but when the economiser is running it can reduce chiller plant energy consumption by up to 70%.

CASE STUDY

HVAC energy savings could be realised by the optimisation of de-humidification systems. A pilot project for the Japanese pharmaceutical manufacturers tested the fitting of an automated bypass on the desiccant de-humidifier on the fresh air servings. When desiccant de-humidification was not required, the de-humidifier would be switched off. This measure resulted in annual energy savings of 1,165 MWh and associated cost savings of €78,000, resulting in a payback period of 1.5 years (EECO$_2$, 2015).

3.4. Lighting

Lighting systems account for about 20% of energy consumption in the average commercial building. Even though this is a small amount of overall consumption, it is usually cost-effective to address lighting as it is often easier to improve its energy efficiency than many process upgrades. Additionally, lighting has a high impact on employee comfort. Care should be taken to maintain or improve comfort levels as this will improve productivity, heath, safety and impact on the general attitude towards an energy efficiency programme (DNV GL, 2012).

- **Replace fixtures with higher efficiency lighting technologies**: Interior lighting conservation efforts should focus on lighting types that produce the highest output (in terms of lumens per Watt of power draw). Incandescent bulbs can easily be replaced with compact fluorescent lamps. By replacing low efficiency fluorescent fixtures (T12, T8) with more efficient fixtures (T8, T5), power consumption can be reduced by 15 to 70%.
- **Install skylights and light pipes**: Install skylights and light pipes to introduce more natural light, and reducing artificial lighting requirements. In warm climates, skylights and light pipes can cause large heat gains. The best applications exist in mild to cold climates, where the heat gains reduce building heating requirements. Skylights facing away from the sun in cold climates can result in conditioned heat loss. Savings vary greatly based on climate.
- **De-lamp fixtures**: Remove unnecessary lamps and disconnect or remove ballasts. De-lamping can result in savings of 0.5 - 5% of total utility costs and is inexpensive to implement.

- **Use time clock, motion sensor or photo controls**: Where lighting is needed on a repetitive schedule, use time clock controls. Where lighting is needed infrequently, use motion sensors for lighting control. Typical spaces where this can be applied include meeting rooms, storage areas, corridors and rest rooms. Photo controls sense ambient light conditions and can be used for interior and exterior lighting (always allow for manual intervention). Savings in the range of 20-70% have been recorded for controlled fixtures. Lamp cost and replacement may be reduced by a similar percentage.

CASE STUDIES

ITC Limited in Bhadrachalam is the largest and one of the best performing pulp and paper plants in India. The plant had a large number of fluorescent tube lights (FTL) with conventional ballasts (high wattage choke). Some of the shop floor locations were lit by old 400 Watt mercury vapour lamps which are less efficient. Due to a lack of control, these lamps were kept burning unnecessarily throughout the day. Moreover, in most of the lighting feeders the single-phase supply voltage was higher than required. To save lighting energy costs, several measures were implemented: replacing the existing FTLs by 36 Watt FTLs equipped with electronic chokes replacing the inefficient 400 Watt mercury vapour lamps with more efficient 250 Watt metal halide lamps, installing automatic timers to optimise the lighting usage, and installing dedicated lighting transformers to facilitate the reduction in lighting voltage levels. These measures resulted in annual electricity savings of 632,485 kWh with associated cost savings of €22,000. The investment cost of €29,000 was thereby paid back within 16 months (UNEP, 2006).

Another energy efficiency case study on lighting is B&Q in the UK, who invested €3.1 million into increasing the efficiency of the lighting in 39 of its stores. Key initiatives included upgrading the old fluorescent lighting to the more efficient T5 variety, together with installing daylight sensors and turning off half the lighting once daylight has reached adequate levels. These measures achieved 20% electricity savings and associated annual cost savings of €1.2 million, resulting in a payback period of 2.6 years (BioRegional, 2015).

3.5. Compressed air

There are two compressor types: positive displacement (reciprocating and screw compressors) and dynamic displacement (centrifugal compressors). Reciprocating compressors have a high efficiency at full and partial load, but waste heat recovery is problematic. Screw compressors have excellent efficiency at full load, but only average at partial load. Heat recovery is easy. Centrifugal compressors have lower efficiency and waste heat recovery is moderately difficult (DNV GL, 2012).

Approximately 90% of the energy input in a compressor ends up as (waste) heat, making compressed air an expensive means of distributing energy (DNV GL, 2012). The follow savings opportunities are possible:

- **Reduce compressed air leakage and remediation**: Identify compressed air leakage and repair the leaks by tightening the connections or replacing leaking equipment. Typical applications have 20-30% loss due to leakage with extreme examples going up to 50%. A 5-15% leakage rate should be obtainable, depending on the size of the distribution network.
- **Reduce pressure set points**: Assess actual consumption level and needs, and reduce pressure to the minimum required level. An adequate control

system should be implemented depending on the characteristics of the system. Rule of thumb: 8% reduction in energy consumption for every bar reduction in output pressure.

- **Maintain compressor condition**: Check the filter condition and insure proper ventilation. Blocked intake filters reduce efficiency. Cooling fins should be free and clean to allow a maximum dissipation of heat. For every 0.0125 bar pressure drop at the suction end, the compressor power consumption increases by about 2% for the same average flow rate.
- **Optimise buffer vessel size**: Correct dimensioning of the buffer vessel should minimise the number of start-ups of the compressor. Consumption peaks can be addressed using a receiver. A smaller compressor at higher load (and thus higher efficiency) can be used. Savings are related to a number of associated problems but are usually in the region of 1-2%.
- **Optimise consumption pattern**: Avoid inappropriate use and switch from air-powered to electrically driven equipment where possible. Electricity use for compressed air driven equipment is approximately five times higher than for electrically driven equipment. Shut off the air supply to "off-line" production equipment. This eliminates losses through equipment and piping leakage.
- **Reduce bag filter cleaning frequency**: A bag filter system contains filter bags through which dust contaminated air is blown. The bags filter the dust from the air flow. To clean the filter cake from the bags, short bursts of compressed air are used to shake the cake loose. A maximum time between pulses should be enforced to prevent the formation of a permanent cake on the bag filter. Increased cleaning intervals decrease the compressed air consumption of the bag filter, improve the lifetime of the bag filters and improve the filtering capacity of the bag filter through the thicker cake.
- **Improve compressor motor efficiency**: Compressors generally have long operating hours. High efficiency motors should be specified. High efficiency motors are typically 2 - 8% more efficient than standard motors.
- **Lower air intake temperature**: Cooler inlet air is denser, resulting in higher efficiency especially for centrifugal compressors. Ensure that the entry of the inlet pipe is situated at a cool location and as free as possible from air contaminants. Every 3°C reduction in inlet air temperature results in a decreased energy consumption by approximately 1% with equivalent output.
- **Recover waste heat**: As much as 80-93% of the electrical energy used by a compressor is converted to heat. Heat recovery systems are available for most compressors on the market as optional equipment, either integrated in the compressor package or as an external solution. For water-cooled compressors, heat recovery efficiencies of 50-60% are possible. For air-cooled compressors, heat recovery efficiencies of 80-90% are possible.

CASE STUDY

Procter & Gamble improved the compressed air system at its paper production mill in Pennsylvania (USA). An assessment had identified some reasons why the system was not operating efficiently, which were mainly related to the compressor control scheme. Each compressor was individually controlled and operated in a manual, fixed output mode. Also, many compressors were at different locations. These conditions made it impossible to determine how an adjustment on one unit affected the operation of the other units, resulting in all units operating at full load, leading to constant blow-off of excess air and pressure fluctuations (DoE, 2004).

The following energy saving recommendations of the assessment were implemented: installing a PLC-based network control system linked to air-flow and dew-point measuring devices to determine when to bring compressors on- or offline, adding piping, eliminating a back-pressure valve, and purchasing a centrifugal compressor to cover the anticipated mill expansion. These measures resulted in annual energy savings of 7.6 million kWh with associated cost savings of €275,000. With a total project cost of €480,000 the payback period was 1.75 years (DoE, 2004).

3.6. Electric motors, pumps, fans and drives

Electric motors account for about 40% of total energy use in commercial facilities and up to 75% in industrial facilities. Assuming a lifetime of 20 years, a motor can use up to 75 times its purchase price in energy cost (DNV GL, 2012). The following energy saving opportunities are possible:

- **Use high-efficiency motors**: Standard single-phase motors typically have an efficiency of 50-60%; standard three-phase motors typically have an efficiency of 60-95%. High-efficiency motors also have higher power factors. If motors fail, always replace them with high-efficiency motors. High-efficiency motors are typically 2-8% more efficient than standard motors.
- **Shut down idling motors**: Adjust (manual or automatic) operating procedures to start up and shut down all motors that are idling. Redundant equipment is often run as a back-up. An automatic start up system can be used in case the primary equipment fails.
- **Use variable frequency drives**: Using frequency convertors, the speed and power of a motor can be adjusted to the required settings. This is especially relevant for fans and pumps as they are typically in continuous operation and throttling or bypass valves are typically used on older systems to control pressure and flow. Do not use variable speed drives when the load does not fluctuate. General estimates are that VFD's save an average of 20-30% of the energy use of the motor.
- **Size motors properly**: Over-sizing of a motor will significantly reduce the efficiency and result in poor power factor. Ensure good loading (i.e. more than 60%) on the motor. Assess actual usage patterns and expected future developments when replacing motors.
- **Use advanced motor control**: For motors that consistently operate at loads below 40% of the rated capacity, an inexpensive and effective measure could be to operate in wye mode. Operating in the wye mode leads to a voltage reduction by a factor of $\sqrt{3}$. The motor is electrically downsized by wye mode operation, but performance characteristics as a function of load remain unchanged.
- **Ensure voltage level and balance**: Voltage unbalance is detrimental to motor performance and occurs when the voltages in the three phases of a three-phase motor are not equal. Voltage unbalance should be kept under 1%. Voltage at the motor should be kept as close to the nameplate value as possible, with a maximum deviation of 5% between the poles. Large variations significantly reduce efficiency, power factor, and service life.
- **Avoid rewinding motors**: If the rewind cost exceeds 50-65% of a new energy-efficient motor price, it is usually more cost effective to buy a new state-of-the-art motor.
- **Replace V-belts with cogged or synchronous belt drives**: Cogged belts are V-belts with notches perpendicular to the belt, reducing the bending

resistance and thus improving efficiency to approximately 98%. Cogged belts can be used instead of V-belts using the same pulleys or sheaves, running cooler and lasting longer. Synchronous belts or timing belts have teeth and require special pulleys to drive equipment. They require less maintenance, operate in dirtier environments and can transfer higher torque because of the reduced slippage. Synchronous belts have approximately 98% efficiency which doesn’t deteriorate over the life of the belt. Typical savings when replacing an older belt with a newer cogged belt are 3% of transmitted energy, if the belt is replaced regularly.

CASE STUDIES

The second largest oil field in China has a total power consumption of 7 billion kWh, over 3 billion kWh of which is related to the use of electric motors. The field had 14,000 motors installed with high power consumption and low energy efficiency, all operating nearly all year round. Replacement of these motors resulted in power savings of 13.2%. The investment cost for one motor replacement amounted to €6,700 and the annual cost savings to €4,100, resulting in a payback period of 1.6 years (UNEP, 2015).

At Deita Extrusion, five motors were replaced with higher-efficiency motors. The energy savings amounted to 12 MWh/year and the associated cost savings to €360/year, resulting in a payback period of the initial investment of 1.6 years (BPMA, 2015).

At Cray Valley, chemicals are stirred inside batch reaction vessels where the speed of stirring is critical. The established method of speed control was a fixed speed motor driving a variable-volume hydraulic pump. However, because VSDs have become more cost-effective in recent years, Cray Valley has been replacing these hydraulic drives with VSDs. This project has demonstrated that VSDs can provide significant cost savings. Replacing two cooling water pumps and a stirrer application resulted in annual energy savings of 360 MWh and associated cost savings of €21,500 and a payback period of 1.9 years (BPMA, 2015).

3.7. Energy management

Organisation-wide energy management programmes are one of the most cost-effective ways to reduce energy consumption. Article 8(6) of the EED therefore exempts large enterprises from the energy audit obligation when they implement an energy management system according to European or international standards, provided that these systems include an energy audit meeting the EED requirements. Energy management programmes help energy efficiency measures reach their full potential by insuring a system-wide approach as well as proper maintenance and follow-up. They also encourage continuous improvement, as opposed to efficiency measures being implemented on an adhoc basis. In companies without a programme in place, improvement opportunities may be missed due to organisational barriers (DNV GL, 2012). Changing how energy is managed by implementing an organisation-wide energy management system (such as ISO 50001 or other programmes) is one of the most successful and cost-effective ways to bring about energy-efficiency improvements. A strong energy management programme is required to create a foundation for positive change and to provide guidance for managing conservation protocols throughout an organisation. Energy management programmes also help to ensure that energy-efficiency improvements do not just happen on a one-time basis, but rather are continuously identified and implemented. Furthermore, without the backing of a sound management programme, energy-efficiency improvements might not reach their full potential due to lack of a system perspective and/or proper maintenance and follow-up. In companies without a clear programme in place, opportunities for improvement may be known but may not be promoted or implemented because of organisational barriers, including a lack of communication among facilities, a poor understanding of how to create support for an energy-efficiency project, limited finances, or poor accountability (DNV GL, 2012).

Employees at all levels should be mindful of energy consumption and company objectives for improvement. Developing "energy teams" with staff from various departments can be especially useful in bringing together the skills and knowledge required to carry out an energy management programmes. Additionally, training programmes for all levels of staff can help introduce energy efficient practices into their daily work routines. Energy management programmes that utilise regular feedback generally have the best results. Savings from one project can be used to fund the next project on the list - this continuous improvement can generate large savings (DNV GL, 2012).

Energy monitoring systems can be an important tool for energy management. These can include sub-metering, monitoring and control systems. These systems can increase product quality and consistency, and improve process operations. This can lead to reduced downtime, lower maintenance costs, shorter processing time, reduced energy consumption and lower emissions. Additionally, monitoring systems play a key role in notifying energy personnel of problem areas within a facility (DNV GL, 2012).

While plants with outdated systems will see the highest savings, advanced control systems are constantly under development and potential benefits exist, even for customers with modern technologies installed (DNV GL, 2012).

CASE STUDIES

Cummins Inc., a global engine manufacturer, successfully implemented an energy management system meeting all ISO 50001 requirements at its Rocky Mount Engine Plant, at an investment cost of €220,000. This cost takes into account the additional costs for internal staff time spent on developing the energy management system and preparing the ISO 50001 audits, the technical assistance, the monitoring and metering equipment, and the third party audit. The company's interest was triggered by the financial returns that a successful system could realise (reduced facility energy bills): utility bills represent a significant share of operating costs at many manufacturing facilities, and as corporations of all sizes strive to cut costs, energy efficiency offers a cost-efficient pathway to financial savings. The energy savings achieved through this system were verified by an accredited third party, resulting in an energy performance improvement of 12.6% spread over three years. The related energy cost savings amounted to €630,000 per year and €281,000 of these savings came from no-/low-cost operational changes. These annual operational savings resulted in a payback period of 11 months for the initial investment cost (US DoE, 2015).

Similar US case studies show comparable results. HARBEC, a specialty plastics manufacturer, for example improved its energy performance by 16.5% over three years, by implementing an energy management system according to ISO 50001. The implementation costs amounted to €110,000. With annual energy cost savings of €45,000 this investment was paid back within 2.5 years (US DoE, 2015).

3.8. Process cooling and heating

For process heating, see section 3.13 (heat and steam generation). For process cooling, see the chiller specific measures from section 3.3 (HVAC).

CASE STUDIES

The Nestlé food processing plant in Pakenham (Australia) was operating its refrigeration system below optimum levels. More compressors were running than were required, there were many unnecessary start/stop operations and some compressors were running only partly loaded. By upgrading the energy management and implementing a mathematically based optimal control system of the refrigeration system, energy consumption was reduced by 16%. The implementation cost of €170,000 resulted in a payback period of six years, when only taking into account the energy cost savings. This investment was funded by the Department of Innovation, Industry and Regional Development, to make the project economically feasible (Nestlé, 2009).

FMC Chemicals Corporation improved the efficiency of two large coal-fired boilers at its soda ash mine in Wyoming (US). The company improved the boiler's operation by upgrading the burner management system. Before this upgrade, a continuous supply of natural gas was required to maintain the appropriate flame conditions: this supply could easily be discontinued without compromising the boiler operation. The upgrade project resulted in annual energy savings of 73 MWh and associated cost savings of €800,000. In addition, the components within the improved burner management system required less servicing, resulting in annual maintenance cost savings of €11,000. With an investment cost of €100,000, the total annual project savings of €811,000 resulted in a payback period of 1.5 months. Moreover, a smaller inventory of spare parts was needed, and boiler reliability and plant safety increased (DoE, 2004).

Sutton Business Centre in the UK provides office and storage space. They decided to replace their old, inefficient gas boiler with two new A-rated condensing boilers, resulting in annual energy cost savings of €1,400 with an associated payback period of the investment cost between two and three years (BioRegional, 2015).

3.9. General maintenance

Keeping systems in good working order will prolong equipment life and ensure its efficient operation. This will lead to lower costs and energy consumption. There are three approaches to maintenance (DNV GL, 2012):

- **Reactive maintenance**: Equipment is run until it fails or breaks down in some way. While this approach requires less staff, it also results in unplanned downtime and increased repair costs since equipment failure will require "emergency" maintenance and associated overtime costs.
- **Preventative maintenance**: Equipment receives periodic maintenance at pre-determined intervals of time. Preventative maintenance aims to detect and mitigate equipment degradation to prolong system life. An example would be changing the oil in an automobile every 5,000 km. This method can be labour intensive but reduces failure, increases equipment life, saves energy and is generally cost effective.
- **Predictive maintenance**: Predictive maintenance takes into account equipment condition when determining maintenance need instead of conducting maintenance activities at time based intervals. Following the automobile example, instead of changing the oil based on runtime, the owner

could have the oil periodically analysed and change it only when it is sufficiently dirty or degraded. This might be 8,000 km instead of 5,000 km. This maintenance strategy will greatly decrease catastrophic failures, allow organisations to schedule maintenance to avoid overtime costs, optimise equipment operation, reduce costs and increase equipment efficiency. Predictive maintenance involves greater initial cost but should be considered the ideal maintenance programme wherever it can be applied.

3.10. Waste heat recovery

Waste heat recovery re-uses heat that would generally be lost or rejected in order to reduce energy consumption in another process. It is generally accomplished by using a heat exchanger that recovers heat from hot waste streams (such as flue gasses or cooling water) and supplies that useful heat elsewhere. There are a number of applications for waste heat, even if it is low quality or low temperature (DNV GL, 2012).

Conventional waste heat recovery includes condensate (heat) recovery, pre-heating input with low-grade heat from used cooling streams, heat grids, fuel cells, etc. Advanced heat recovery includes mechanical and thermal vapour recompression, Organic Rankine Cycle (ORC), combined heat and power (CHP), etc. (DNV GL, 2012).

CHP or cogeneration is a highly efficient process that captures and utilises the heat that is a by-product of the electricity generation process. By generating heat and power simultaneously, CHP can reduce carbon emissions by up to 30% compared to the separate means of conventional generation via a boiler and power station. The heat generated during this process is supplied to an appropriately matched heat demand that would otherwise be met by a conventional boiler. CHP systems are highly efficient, making use of the heat which would otherwise be wasted when generating electrical or mechanical power. This allows heat requirements to be met that would otherwise require additional fuel to be burnt (DNV GL, 2012).

ORC uses an organic, high-molecular mass fluid, with a liquid-vapour phase change or boiling point at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds, etc. The low-temperature heat is converted into useful work, which can be converted into electricity (DNV GL, 2012).

Vapour compression evaporation is the evaporation method by which a blower, compressor or jet ejector is used to compress, and thus increase the pressure of the vapour produced. Since the pressure increase of the vapour also generates an increase in the condensation temperature, the same vapour can serve as the heating medium for its "mother" liquid or solution being concentrated, from which the vapour was generated to begin with. If no compression was provided, the vapour would be at the same temperature as the boiling liquid/solution, and no heat transfer could take place. If compression is performed by a mechanically driven compressor or blower, this evaporation process is usually referred to as Mechanical Vapour Recompression (MVR). In case of compression performed by high pressure motive steam ejectors, the process is usually called Thermal Vapour Recompression (TVR). MVR and TVR are proven energy-efficient methods of heating/drying that have been employed worldwide (DNV GL, 2012).

CASE STUDY

The Südbayerische Portland cement plant (Germany) has an innovative commercial-scale plant for the reduction of nitrogen oxide emissions (NOx) built, which uses the waste heat of the cooling air from the clinker production. Cement clinker is manufactured in a high temperature process that is associated with a high specific energy consumption and high NOx emissions. By selective catalytic reduction (SCR), the proportion of NOx emissions in the exhaust gases is greatly reduced. The plant heats the kiln exhaust gas by using a smart waste heat utilisation. A new pendulum grate cooler allows the use of waste heat from the clinker cooler, and a catalyst to the process downstream heat exchanger makes it possible to use the exhaust residual heat. The plant saved 20 GWh/year (corresponding to 2.2% energy savings for the entire plant and 97% energy savings compared to a conventional SCR system), thereby annually saving €432,000 on energy costs. The investment of €1.2 million is thereby paid back within 2.8 years (DEnA, 2012).

3.11. Automation

Improved automation**,** process control and operation (software and hardware) can help to reduce electricity consumption significantly, while also providing additional benefits of improved productivity, reduced costs, and increased equipment life time. Modern controls using a multitude of sensors can achieve these to a greater extent than older controls. Such modern systems integrate real-time monitoring of process variables, such as reactor temperatures, carbon levels, etc. Neural networks or "fuzzy logic" systems, for example, analyse data and emulate the best controller. Statistical analysis afterwards (data mining) can also reveal correlations and process inaccuracies (DNV GL, 2012).

CASE STUDY

IBM, a multinational computer technology and IT consulting corporation, implemented an enterprise energy management system to enable real-time energy use monitoring at all IBM locations. IBM's energy conservation programme provided an effective methodology for performing ongoing optimisation of building and system operations that would utilise real-time baseline energy use from a regular, periodic (every 15 minutes) collection of building, system and facility level electrical use. Collection of electrical use data over the day provides a view into two important factors: anomalies in energy use such as short-term transients of high electrical use, and increases in electrical use over time against a baseline electrical use profile. The system resulted in the identification of over 100 energy conservation projects in 2005 and 2006, resulting in total electricity savings of 16,500 MWh and associated cost savings of €1.2 million (ICC, 2009).

3.12. Waste reduction

Waste reduction includes materials recycling through supply chain collaboration and material loss reduction during production.

Recycling of materials has become common practice in recent decades, with households in many countries encouraged to save used cans, glass, plastics, paper and garden rubbish for special collection. These are then recycled for two main reasons. One is local, to save land which would otherwise be used for disposal of the waste. The other main reason for recycling has a global significance, i.e. to help conserve valuable resources, such as metals, wood and energy (DNV GL, 2012).

Material loss reduction is a general term to describe the process of systematically reducing losses at the source. It covers raw material and ingredient use, product loss, water consumption and effluent generation, paper and packaging, factory and office consumables, all other solid and liquid wastes, gaseous emissions and wasted effort. Companies that take steps to reduce the amount of losses generated do not only save the costs of managing these losses, but also make much greater savings on the cost of inputs to the production process. Reducing losses is therefore essential to maintaining business competitiveness. It also makes good business sense to reduce waste disposal costs by looking at ways of producing less waste (DNV GL, 2012).

3.13. Heat and steam generation

Like any secondary energy carrier, steam is costly to generate. Steam distribution systems can be major sources of energy loss at any industrial plant. However, energy saving measures are simple: retain and recover as much heat as possible. There are three main boiler types: fire tube, water tube and electrical boilers (uncommon and therefore not addressed here). Typical boiler efficiencies range from 62-70% for an older boiler, 80-88% for a new boiler and 89-99% for a condensing boiler using natural gas (DNV GL, 2012).

This category covers energy saving opportunities related to combustion, burners and (industrial) furnaces as well as steam distribution (DNV GL, 2012).

- **Optimise furnace/combustor pressure**: Furnace draft, or negative pressure, is created in fuel-fired furnaces when high temperature gases are discharged at a level higher than the furnace openings. Operating furnaces/combustors at unnecessarily low or unstable negative pressure disturbs combustion control and leads to excessive air infiltration. Estimated energy savings from maintaining furnace pressure control are 5-10%, and this measure can also improve product quality.

- **Reduce excess air in combustion**: Reducing air excess (O_2 concentration in flue gas) increases boiler efficiency (lower stack loss). Limiting factors are safety, incomplete combustion (CO, C_xH_y emission), boiler corrosion and fouling. Online oxygen analysers and oxygen 'trim' systems providing feedback to the burner controls are recommended in the case of highly variable fuel composition or highly variable steam flows. Proper air-to-fuel control can yield savings of 5-25%.

- **Pre-heat combustion air**: Combustion air pre-heating is often a suitable candidate for 'low-temperature' (waste) heat recovery, e.g. from flue gas. Air pre-heaters can raise efficiency of combustion by 3-5%. If pre-heating is done by heat recovery from flue gas, estimated saving potential is 10-30%.

- **Enrich combustion air**: Enriched combustion air (i.e. O_2 concentration > 21 vol %) reduces stack-loss and therefore increases efficiency. Estimated saving potential is 5-25%, depending on oxygen cost.

- **Upgrade burners**: Older, wrongly sized, or mechanically deteriorated burners are typically inefficient. These inefficiencies result in incomplete combustion (high carbon monoxide (CO) emissions and unburned carbon) and the need for high excess air. Sophisticated combustion monitoring and controls should be an integral part of an upgrade. Many suppliers offer burner retrofit parts for modifying burners rather than fully replacing them; this can often achieve significant improvements at a much lower cost than a full replacement. This can result in savings of 5-10%.

- **Pre-dry or pre-heat fuel**: Pre-drying or pre-heating of fuel (typically 'lower grade' solid fuels such as lignite, biomass, peat) or pre-heating of fuel (typically gas or oil) increases efficiency, mainly by reducing the moisture content in the off-gas. Efficiency increases of 2-7% have been reported.

- **Recover waste material as fuel**: Depending on the suitability and the availability of the waste streams, considerable cost savings can be achieved.

- **Insulate steam pipes**: Insulating steam pipes is generally a low cost measure with energy and safety benefits.

CASE STUDY

At certain chemical plants, steam systems account for the most end-use energy consumption. By conducting energy assessments of their steam systems, these plants can uncover important opportunities to improve energy efficiency, leading to significant savings, lower emissions and higher productivity. An energy assessment carried out at Dow Chemical's petrochemical plant in Louisiana (USA) quantified several opportunities for increasing the steam system efficiency. The site improved its steam trap programme and enhanced its ongoing leak repair campaign. These two measures resulted in annual energy savings of 80,000 MWh with associated cost savings of €1.7 million. The investment cost of €200,000 was thereby paid back within 1.5 months (DoE, 2007).

3.14. Other measures

Other measures that do not fall into any of the above categories can be general, facility wide measures as well as highly specific measures for certain industries or sectors. Since this report is meant to be a broad guide, we have not included any niche applications here, only the measures that could be implemented across a wide range of facilities.

- **Reduce peak demand**: A reduction in peak load often results in large monetary savings for organisations with time of use billing. This measure is, however, not an energy efficiency measure, as it does not reduce the overall energy consumption but only shifts the demand in time (DNV GL, 2012).
- **Total site pinch analysis**: Pinch analysis can be an important tool to significantly improve efficiency in plants with multiple heating and cooling loads. This analysis involves connecting a process's hot and cold streams in a thermodynamically ideal way (and not over the "pinch"). Pinch analysis utilises a systematic approach to finding and correcting the pinch in any manufacturing process. It uses "composite curves" for heating and cooling that represent thermal demand and availability for a given process. Drawing these curves on a temperature-enthalpy graph reveals the process pinch and the minimum heating and cooling requirements. These are the energy targets. Once the targets are identified, heat exchanger networks are developed to meet these targets. This approach can be applied to new plants and retrofits of existing plants. This method can produce savings of 20-30% of total site energy consumption (DNV GL, 2012).
- **Install efficient transformers**: Installing newer, more efficient transformers can minimise energy waste and result in savings of 1-3% of total site electricity use (DNV GL, 2012).
- **Fuel switching**: Switching away from heavy fuel oil or a solid fuel can greatly reduce CO_2 emissions. Natural gas or other low emission fuels are recommended (DNV GL, 2012).
- **Industrial clustering**: Clusters are groups of inter-related industries in a defined geographic area, sharing common markets, technologies, worker skill needs or buyer-seller relationships. By clustering local industries, energy costs are shared, heat and resources are used wisely and benefits increase.

Connecting industrial sites close to each other allows efficient use of energy and materials (DECC and BIS, 2015).

- **Process intensification**: Deployment of short- and long-term process intensification techniques (such as miniaturisation and creating synergies between process steps) optimise energy use. Short-term examples include: static mixers, static mixers-reactors, other structured catalytic reactors, hex reactor, rotating packed beds, micro-channel heat exchangers, multi-stream heat exchangers, reactive distillation, OBFR/OBFC, buss loop reactors, ejector- or Venturi-based reactors, micro-mixers, rotor-stator mixers, etc. Long-term examples include: membrane absorption/stripping, pervaporation assisted reactive, centrifugal extractors, extractive distillation structured internal for mass transfer, membrane extraction, impinging streams reactors, distillation-pervaporation systems, centrifugal adsorption technology, foam reactors, reactive crystallisation/precipitation, MIP, SMBP, spinning disc reactors, heat-integrated distillation, reactive absorption, membrane reactor, pulsed chromatographic reactors, hydrodynamic cavitation reactors, pulsing operation of multiphase reactors, millisecond reactors, ionic liquids, adsorption distillation, nano-filtration, microwave reactors non-catalytic, etc. (DNV GL, 2012).

CASE STUDIES

Alcoa North American Extrusions conducted a power factor study at their facility in Utah (US). The facility was paying approximately €4,500 power factor penalty[2] each month and wanted to reduce this. It also wanted to improve the efficiency and capacity of the plant's electrical distribution system and the productivity of the equipment it serves. The study recommended installing additional capacitators, which resulted in a power factor improvement from 70% to 90%, leading to virtually no more penalties. The project's cost of €50,000 paid for itself in less than 1 year (DoE, 2001).

The city of Ghent (Belgium) developed and analysed an ambitious low-carbon energy issuance policy for business park Wiedauwkaai. At the moment, the area is not optimally exploited and the city of Ghent wants to transform it into a suitable and qualitative local business park with green zone. The city wants to attract manufacturing company clusters that will exploit opportunities in industrial symbiosis (inter-firm cooperation in terms of resources, energy and waste). Other examples of these clustering initiatives can be found in the ACE - Answers to the Carbon Economy - project, seeking to find practical and economic solutions at three levels: individual businesses, business-to-business relationships and business parks (ACE, 2015). The actual saving potential from these clustering initiatives still has to be demonstrated, as the projects have only recently started running, making it too soon to already draw conclusions.

Ferso-Bio is a French company collecting and transforming animal waste and by-products. Their fleet of 132 vehicles transports this waste from four different sites to the processing plant daily, thereby consuming 14% of the company's total energy use. To reduce this energy consumption, the company has provided its drivers with eco-driving training and deployed an automated system to optimise the logistic schedule. The investment costs of €308,000 were paid back within five years by the annual fuel

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[2] A power factor is a measure of how effectively equipment is converting electric current into useful power output. It is the ratio of active or useable power (in kW) to the total power (in kVA), both active and reactive. The power factor of an equipment can be improved by installing corrective capacitates. Equipment with a low power factor demands significantly more power than it is actually using. Utility companies often charge users a penalty when their power factor drops below a certain level.

savings of 637 MWh (63,383 litres of gasoil) and the associated annual cost savings of €60,000 (Ademe, 2015).

3.15. Implementation of energy audit recommendations

Identifying energy saving measures through energy audits is one thing, but actually implementing the opportunities is often a completely different story. Article 8 of the EED and the implementation of the audit obligation into national legislation do not require large enterprises to implement any audit recommendations, which might be a pitfall in the aim to increase energy efficiency in Europe. Member States could go beyond the EU minimum requirements by making the implementation mandatory, but currently no such examples have been found that are applicable to all large enterprises. However, certain Member States (such as Italy, Portugal, Belgium (Flanders) and Romania) do have a mandatory requirement for the implementation of audit recommendations, but this is only applicable to energy-intensive companies.

A good practice example encouraging the implementation of identified energy saving measures are the Learning Energy Efficiency Networks (LEEN). In the 366 companies participating in the 30 Pilot networks project, 7,030 measures were identified, 3,580 of which seemed profitable (with an IRR greater than 12%), resulting in an energy saving potential of 2670 MWh/year. Preliminary results (as many networks are still in operation and the evaluation process has not been completed) on the evaluation of implemented measures show that 207 measures (6% of the economically feasible potential) have been implemented and 98.5 MWh/year energy savings (4% of the savings potential) have been achieved (Köwener et al., 2014). Despite the success of LEEN, it seems difficult to convince participating companies to implement identified saving measures and take advantage of the full potential.

Another example also focussing on SMEs is the Sonderfonds Energieeffizienz in KMU or the Energy Audit Scheme for SMEs in Germany (Fleiter et al., 2012). This scheme was established in 2008 and offers grants to SMEs to conduct energy audits. An evaluation of the first two years of this programme shows that the energy audit recommendations resulted in a net adoption rate of 43% (resulting in energy savings of 230 GWh/year) when measures that had already been planned before the audits are excluded, and up to 72% (resulting in energy savings of 395 GWh/year) when these measures are included. Fleiter et al., (2014) also compared these results with other energy audit programmes for SMEs worldwide. The IAC programme in the USA reached 50% adoption of identified measures, the EEAP programme in Australia reached 81%. Project Highland in Sweden, however, only reached 22% adoption when excluding measures that had already been planned before the audits and up to 41% when including them. Differences in these adoptions rates are due to differences in the number of measures initially recommended, the size of the companies, the types of recommendations, etc., making it very difficult to directly compare results.

The **Energy Audit Scheme for SMEs** was launched in 2008 by the German Ministry of Economic Affairs, targeting SMEs in all sectors. The programme includes two types of audits which can be combined or used separately: (i) a screening audit lasting 1-2 days, including a short check of the energy-consuming equipment, giving recommendations for improvement, and being subsidised for 80% of the total audit cost, and (ii) a comprehensive audit taking up to 10 days, including a detailed inspection and suggestions for energy efficiency measures, and being subsidised up to 60% of the audit cost.

Other good practice examples (which might be more effective) are the voluntary agreements available in several Member States. These agreements include energy audits and the mandatory implementation of (economically viable) saving measures, such as the *klima:aktiv pakt 2020 programme* in Austria, the *EnergieBeleidsOvereenkomst* (EBO) in Flanders (Belgium), the *Accords de Branche* (AdB) in Wallonia (Belgium), the *Energy Agreements Programme* (EAP) in Ireland, and the *MeerJarenAfspraak* (MJA3) and the *Meerjarenafspraak Energie-efficiëntie ETS ondernemingen* (MEE) in the Netherlands.

The **klima:aktiv pakt 2020 programme** is Austria's climate pact created by the Austrian Ministry of Agriculture, Forestry, Environment and Water Management. It is a voluntary programme in which participants are committed to putting integrated concepts into practice to reach the Austrian climate goals for 2020. The foundation of achieving these goals is laid by a catalogue of measures that need to be undertaken by 2020, and companies volunteering to participate need to implement these measures into their own concepts and strategies. During the affiliation process, companies need to prove their pioneering role in energy efficiency and the use of renewables. Within six months, they need to develop a detailed climate protection concept (34% share of renewables in total energy consumption, 10% share of renewables in mobility-based energy consumption, 20% increase in energy efficiency, and 16% reduction of CO_2 emissions compared to 2005) and an internal energy management system for monitoring purposes. After admission and approval of the concept, companies can become official partners of the klima:aktiv pakt 2020. Pact partners are supported by technical workshops (on energy efficiency, renewable energy sources, sustainable resource use, mobility and behavioural aspects), strategic assistance in developing climate protection concepts, benchmarking databases, ISO 50001 training, detailed guides and tools for energy auditors, branch studies, conferences, etc. (Klima:aktiv, 2015).

Companies entering into the **EBO** in Flanders are committed to carry out a four-yearly energy audit and develop an energy plan based on these audit results: a first energy plan for the first three years of the agreement, and a second energy plan for the remaining period of the agreement. The energy plan then has to be conducted in phases throughout the EBO period: every economically feasible energy saving measure (with an IRR of at least 12.5% for non-EU ETS companies and 14% for EU ETS companies) needs to be implemented. Companies need to annually report to the Verification Office VBBV on implemented measures, studies and calculations of potentially economic measures, as well as on their energy use, CO_2 emissions and the evolution of both (at the latest on 1 April of every year). They need to carry out a feasibility study on CHP, and cooling and heating networks. And they need to implement an ISO 50001 energy management system within three years after entering the agreement, or implement other energy management measures (developing an energy policy, assigning an energy representative, and informing and engaging employees) within that same period. Flemish government, in return, is committed to not impose additional energy or CO_2 taxes, or extra energy efficiency or emissions reduction targets on participating companies. Any non-conformity with the requirements can result in the exclusion of a company from the EBO (EBO, 2014).

In the early 1990s, the Walloon Region proposed to the industrial sectors to participate in voluntary agreements to reduce their greenhouse gas emissions or improve their energy efficiency. These voluntary agreements were called '**Accords de Branche**'. Several industrial sectors have engaged in these agreements: chemicals, paper, steel, glass, cement, etc. The agreements create real partnership commitments between the Walloon Region and industry, represented by their trade associations. Industry commits itself to certain energy performance improvements, and in return they receive several financial incentives and administrative advantages from the region. Companies participating in the agreement receive a subsidy of 75% to carry out an energy audit, are not imposed with any other additional regulatory measures regarding energy and greenhouse gas emissions, and they might be exempted from the energy tax in the future (currently under discussion on European and Belgian level) (Energie Wallonie, 2015). To participate in the ‘Accords de Branche’, a company and its trade association need to take several steps: (i) sign a declaration of commitment between the company and its trade association; (ii) carry out an energy audit on each industrial site to identify the energy saving potential (company); (iii) define an objective for improving the company’s energy efficiency or reduce its greenhouse gas emissions, and develop a plan to reach this objective (company); (iv) determine the sectoral objectives by consolidating the individual company objectives, and thereby develop the branch agreement (trade association); and (v) implement the branch agreement, by implementing the identified opportunities and annually reporting on the performance improvements (company), and by specifying the arrangements for monitoring and the penalties for non-compliance (trade association) (Energie Wallonie, 2015). The ‘Accords de Branche’ of the first generation started in 2003 and lasted until 2013. Over a ten year period, 172 companies and 205 operating locations across 16 agreements in 13 industrial sectors participated and successfully met their objectives. These companies represented over 75% of the energy consumption of the Walloon Region, and results exceeded expectations: the energy efficiency of Walloon industry has improved by 16.5% and greenhouse gas emissions have been reduced by 19.3%. Due to this success, the second generation of the ‘Accords de Branche’ started in 2014 and will run up to 2020. This second generation still involves monitoring of energy consumption and objectives to improve energy efficiency and reduce greenhouse gas emissions. But it is also more systematically open to the possibility of using renewable energy sources on industrial sites and to life cycle analysis of energy and CO_2. 158 companies have already signed up (AwAC, 2015).

The Large Industry Energy Network (LIEN) is a voluntary grouping, facilitated by the Sustainable Energy Authority of Ireland (SEAI), of companies working together to develop and maintain robust energy management. 166 of Ireland’s largest energy users are members of LIEN, representing approximately 17% of the national total primary energy requirement and an annual energy spend of €1.1 billion. On average over the last five years, LIEN has achieved annual energy performance improvements of approximately 1%. Members who joined the network in 1995 have achieved an improvement in energy performance of 27% compared to the year they joined. Regular networking events, workshops, seminars and site visits provide the opportunity for members to meet and learn from specialists, including energy experts, and also from their fellow energy managers on the solutions that work. By learning from experts and sharing knowledge and experiences, members save valuable research time, invest wisely and maximise returns (SEAI, 2015). Over 70 of the LIEN companies are also members of the **Energy Agreements Programme** (EAP), which is a subset of LIEN. Major energy users can voluntarily commit to manage their energy use in a strategic and systematic way, supported by SEAI to implement an energy management system through the ISO 50001 standard. Companies agree to implement ISO 50001 and pursue an aggressive programme of energy efficiency actions and investment. In return, during the initial three-year period of the agreement, the companies receive tailored support from SEAI in the form of assigning an Agreements Support Manager to provide both general and technical advice, assessing any gaps in order to achieve ISO 50001, identifying special investigations to reveal opportunities for energy savings, providing ISO 50001 implementation support, and organising tailored workshops, training and network events (NEEAP III Ireland, 2014).

Companies participating in the **MeerJarenAfspraak** MJA3 in the Netherlands are required to develop, implement and annually report to SenterNovem on an energy efficiency plan (EEP). Cost-effective measures are defined as measures with an IRR (internal rate of return) of 15% or a payback period of five years or less. Such measures defined in the EEP need to be implemented to increase the energy efficiency within the organisation. The company also needs to implement an energy management system according to the "Reference Energy Management" (ISO 50001 is suggested as good practice but not mandatory (Mijn Energiezorg, 2015)), at the latest three years after joining the agreement. In return, no additional regulations regarding energy efficiency or CO_2 reduction will be imposed on participating organisations. Organisations that do not meet the mandatory requirements of the agreement will be excluded from the MJA3 and will be imposed with stricter regulations to obtain an environmental permit (MJA, 2008), and will be refused their progress statement which is needed to receive energy tax refunds (RVO, 2015). ETS companies participating in the **Meerjarenafspraak Energie-efficiëntie ETS ondernemingen** (MEE) are also required to develop and implement an EEP. This plan needs to include measures to increase energy efficiency and a target to increase the overall energy efficiency and reduce carbon emissions by implementing certain cost-effective measures. The implementation of an energy management system is not mandatory, although it is recommended. Organisations that do not meet the mandatory requirements of the agreement will be excluded from the MEE and will be imposed with stricter regulations to obtain an environmental permit (MEE, 2009), and will be refused their progress statement which is needed to receive EU ETS compensations (RVO, 2015).

These voluntary agreements, which are often focussed on energy-intensive industry, have proven to be very effective in increasing a country's energy efficiency. These good practice examples should therefore be considered for use in encouraging other Member States to take a similar approach, and encouraging large enterprises to implement energy audit recommendations. However, the scope of these voluntary programmes should be broadened to also target large enterprises which are less energy-intensive.

4. Conclusions

As shown in section 2 of this report, defining average costs for energy audits in different Member States is not an easy task. In theory, these costs would depend on the company characteristics and the type of audit required (buildings, industrial processes or transport), as well as on the size of the organisation to be audited and its energy-intensity. In practice, many other parameters seem to influence the hours and efforts spent by the auditors and therefore the typical audit prices.

Auditors need to work with real energy consumption data and company characteristics, often have to "hunt down" the necessary data, verify obtained data or even provide special measurements when information is lacking. The availability of correct company information is therefore of significant importance when determining the energy audit cost.

Differences in audit costs are also apparent in different Member States. Tax laws, the general cost of living, energy costs, reporting requirements, auditor qualifications, etc. are all very important issues influencing audit costs. Based on the limited cost data available, it is, however, not possible to draw general conclusions regarding the price differences in different Member States.

The library with typical energy saving measures could be a helpful tool for companies in their search to energy efficiency opportunities. It should, however, be noted that the library is an overview tool, and only provides estimated savings (and costs where available). It is by no means the ultimate guide to increasing energy efficiency in companies, but merely an overview of some common measures to be taken.

Several Member States have (or are in the process of) developed an online tool or application, which has to be used by large enterprises or energy auditors to upload the results of the mandatory energy audits. Monitoring bodies typically request information on the auditor and the audit recommendations (amongst other information). These national web applications could be a very helpful tool in the development of a more complete and accurate European-wide database, listing the most common audit recommendations and also providing accurate and more in-depth information on the energy audit costs in different Member States, and the basis of these price calculations. This report can be seen as a first step towards the development of such a European database, which could go hand in hand with the suggested European register for energy auditors (cfr. Task 4 report).

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