Energy and English Wine Production

(A review of energy use, benchmarking and good practice)

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Executive Summary

The UK wine production industry, with more than 120 wineries, has many challenges linked to its northerly cool climate conditions and youthful status as a quality wine-producing country. However, the subject of sustainability remains important for producers, particularly as a means of improving the economic viability of wine production.

There are many different systems, spaces and processes required in the modern winemaking facility. Each of these activities have a role within the modern winemaking facility and have a corresponding energy requirement, which collectively relates to an energy input necessary to produce the finished product. This report presents energy usage within UK winemaking facilities based upon a representative number of energy audits conducted at an individual winery level including a walk-through energy survey (visual inspection and information relating to installed equipment and operating processes) of the winemaking facility and (where possible) at least 3 years historic production figures, utility use and distribution. The survey did not include vineyard operations or energy usage. The wineries surveyed were representative of the geographic distribution of producers in the UK and included a range of production scales from a few thousand bottles per year to over 300,000 bottles per year.

The combined (average yearly) bottle production for the wineries surveyed was 1,032,194 bottles, representing almost 26% of the total wine production capacity in the UK, expending 512,350 kWhs of energy. Extrapolating the study findings to the entire English winemaking industry (winery only) indicates that 2,008 MWhs of energy was expended in 2011, which is equivalent to the energy released by burning 1181 barrels of crude oil. In approximate terms, this is equal to the annual energy use of 200 households in the UK per year, producing 736.8 tonnes of CO_2 per year, the same emissions from a family sized car travelling 2,211,137 miles. The average energy benchmark for UK wine production is 0.557 kWh/litre, ranging from 0.040 kWh/litre to 2.065 kWh/litre. This value compares favourably with other wine producing regions, although a number of wineries globally have demonstrated that much lower values can be attained, indicating that there is still a substantial reduction in energy usage potentially available within the English winemaking industry.

As the cost of energy increases, public perceptions about energy use evolve and as the English wine industry expands, it is increasingly important, from economic, environmental and social perspectives, that good energy management and use is widely adopted by producers. In the final section, this report adds information, guidance and examples on the important subject of energy and good practice, to further support the sustainable development of the UK wine production industry.

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Acknowledgements

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1.0 The English Wine Industry

The UK wine production industry expanded rapidly from under 800ha of established vineyards in 2005 to over 1300ha in 2012, with more than 120 wineries, it continues to grow. The wines produced are aimed at the premium market; with Sparkling Wines at the price-points occupied by good Champagne. Global warming, modern viticulture and oenology technology, and an improved skills base have all contributed to the growth of the industry in the UK.

The UK has grape and wine production challenges linked to its northerly cool climate conditions and youthful status as a quality wine-producing country. However, the subject of sustainability remains important for producers, particularly as a means of improving the economic viability of wine production (Laurence Gould Partnership 2012). Integrated and sustainable wine production initiatives worldwide focus on environmental impact reduction and resource protection that are borne out of market demand, fiscal efficiency imperatives, regulatory or legal drivers and increasing awareness of environmental and climate concerns (Forbes et al. 2009). UKVA and WineSkills initiatives have begun to address issues of sustainable production through training, policy and guideline development, to help producers managing their businesses in ways that reduce environmental impacts, improve economic viability and ensure good stakeholder relations. This report adds information, guidance, examples and critical benchmark data, on the important subject of energy, to further support the sustainable development of the UK wine production industry.

1.1 The Energy issue

Climate change and its potential impact is one of the greatest challenges facing mankind today. Viticulture and winemaking, much like the ski industry, are climate change bellwethers as both are highly dependent upon the weather, climate and place. The sensitivity of vines to climate is illustrated in their use as proxy indicators of past climates (Chuine et al. 2004). Any future changes in the seasons, extreme weather events, duration, local maximum, minimum and mean temperatures, frost occurrence and heat accumulation could have a major impact on the winegrowing areas of the world. These changes are already evident in the form of increased vineyard plantings in traditionally extreme northerly viticultural regions, such as southern England, or the pole-ward movement and plantings of varietals suited to intermediate or warm climates.

Grape growing and wine production is a global industry, representing a significant demand on the world's resources, including fossil fuels. In 2009 7660000 hectares (18920000 acres) were under vines (Anon 2010b) producing 268.7 million hectolitres of wine (Anon 2010b). Even though the production and transport of wine only makes up 0.08% of global green house gas emissions or about 2kg of greenhouse gas per 0.75 litre bottle, the industry has a great deal at stake (Colman and Paster 2009). It could be argued that the wine production industry given its energy requirements, subsequent emissions and the detrimental effects that climate change may bring to the industry, should be at the forefront in promoting energy efficiency and the adoption of renewable technologies.

1.2 Environmental Drivers

Most of the world's wine producing regions are found within the temperate latitudes of 30° and 50° in both hemispheres, though altitude and proximity of large bodies of water can impact the meso-climate. Figure 1.1 illustrates the global location of significant wine producing regions (black shading) and the average annual temperature isotherms for 10ºC and 20ºC in both hemispheres. The risk to vineyards (and thus the wine industry) is obvious if there is any movement of the upper and lower hemispherical isotherm lines towards their respective poles. In the southern hemisphere the risk to South African and Australian wineries is apparent as both countries have limited capacity to adapt to climate change through spatial migration. Only South America and New Zealand stand to make any gain in this scenario. Similarly, in the northern hemisphere, there is a risk to the American wine industry but the change may be even greater for the southern European wine producing areas which have the additional challenge of regional identities being strongly tied to wine types.

Of course, as changes in the climate and its impact on the winegrowing regions increases, like any dynamic business, the wine industry will seek to adapt. Whilst climate change may shift the ideal winegrowing locations into new regions, leading to new plantings and wineries, and some wine producers already in extreme regions may go out of business, many wine producers will have to adapt to the changing conditions by adopting new practices or planting more appropriate varietals. Environmental drivers offer a strong argument for moving towards wineries that are energy conscious and adopt good energy practice.

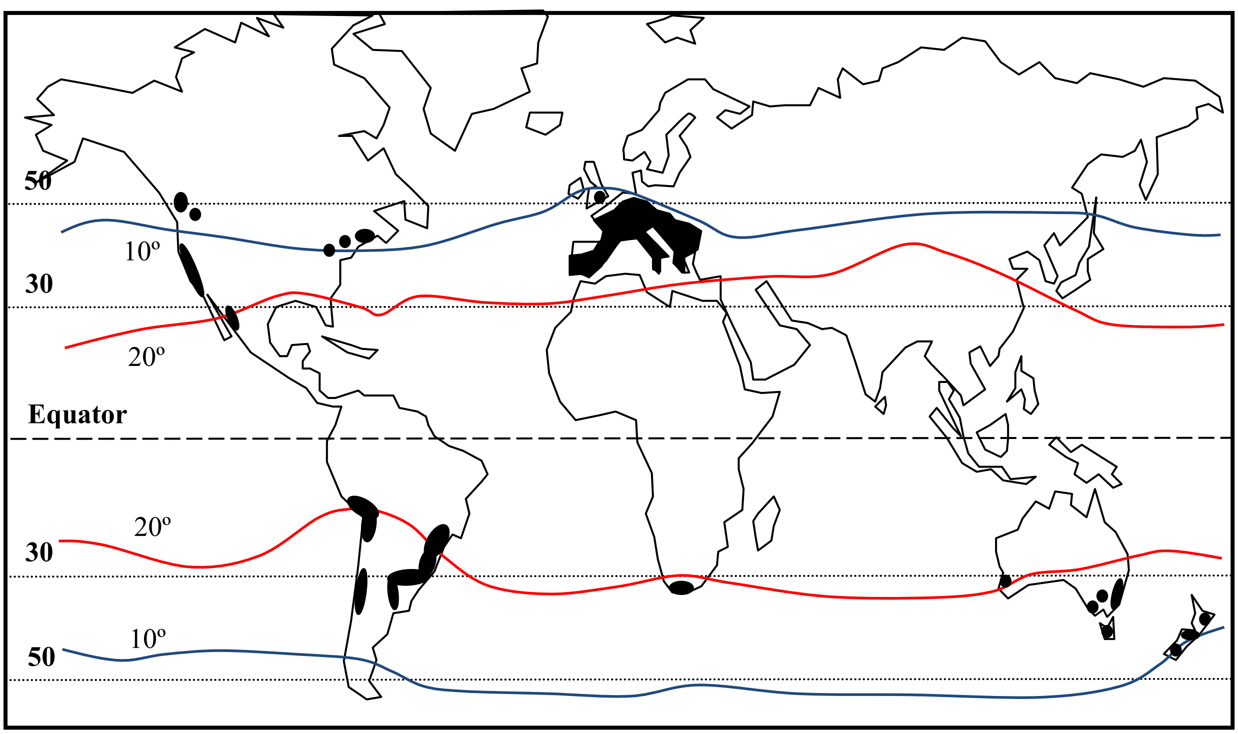


Figure 1.1: Principle (developed) wine producing regions of the world with present isotherms

1.3 Economic Drivers

Economic drivers for energy efficiency and renewable energy in the winemaking industry could be purely financially driven through rising fuel costs and the downward trend in the cost of renewable technologies. However, for many, these conditions on their own are not enough of a ‘financial carrot’ to induce a significant uptake in energy efficient practice and renewables. In response, many of the (wine producing) nations throughout the world have sought to use financial incentives, either directly or indirectly by legislative action to promote the deployment of energy efficiency and alternative technologies.

1.3.1 Rising energy/fuel costs

Rising energy/fuel costs and increasing instability of fuel markets provide a direct economic incentive to move towards energy efficient operation and renewable energy sources. Whilst this phenomenon is global, its impact is not uniform, with some regions and industries being affected more than others. Figures 1.2 to 1.4 show the relative price increases in natural gas, electricity and gasoline for major wine producing regions of the world (New Zealand, Europe, South Africa and the USA) from 2001 to 2008.

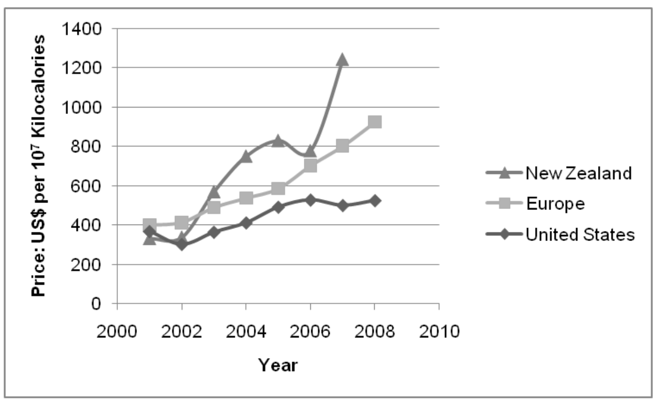


Figure 1.2: Trends in Natural Gas Prices for 3 wine producing nations (adapted from DOE/EIA 2010)

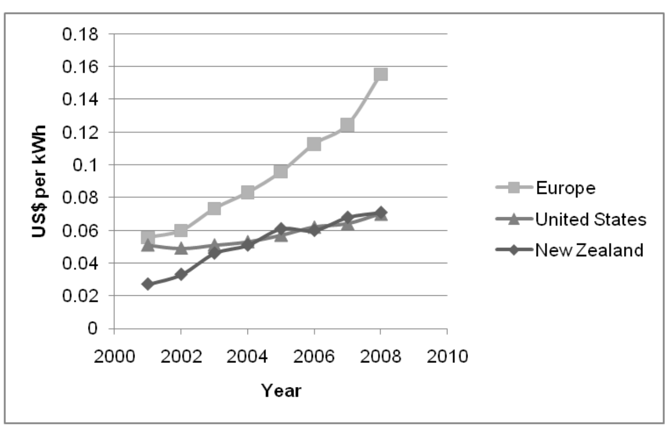


Figure 1.3: Trends in Industrial/Commercial Electricity Prices for 3 wine producing nations (adapted from DOE/EIA 2010)

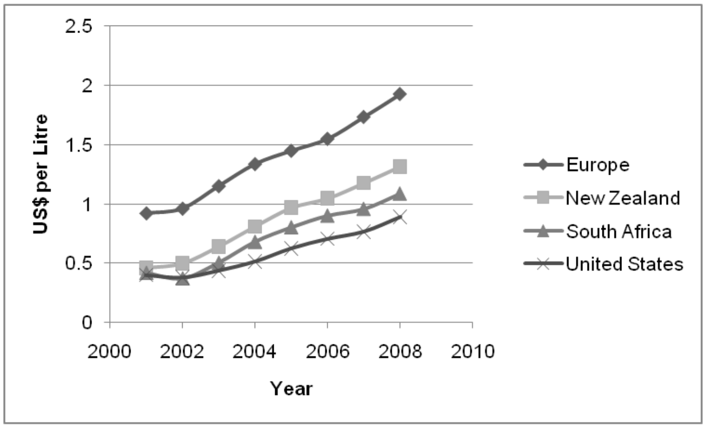


Figure 1.4: Trends in Gasoline Prices for 4 wine producing nations (adapted from DOE/EIA 2010)

It is clearly evident from these figures that the trend in energy costs for all regions is upwards with significant variation in the rate of increase. The 'globalised' wine industry is very much dependent upon fossil fuels and any future rises will have a major impact upon production and transportation costs and ultimately, perhaps the economic sustainability of some producers. Of course, the level of impact will be highly variable depending upon winery location, level of mechanisation and processes, practices and product price.

1.4 Political drivers and financial incentives

Political and legislative action has the potential to drive huge changes in the overall carbon intensity of industries and possibly the cost of doing business. The wine industry, as previously mentioned, is estimated to produce only 0.08% of global greenhouse gas emissions. Given this scale, the industry may not be an obvious target for direct legislative action aimed at reducing emissions. However, vineyards and wineries are directly dependent upon several industries with larger carbon footprints such as power generation, transportation, glass production and the fertilizer/pesticide manufacturing industries. In addition, the potential for an across the board carbon tax or a cap and trade system could directly impact the industry.

Currently there is no uniform global agreement on how to legislatively manage carbon emissions. However, three distinct methods or systems have become common including:

- Direct reduction in energy consumption through energy efficiency improvements
- Reduction in the carbon intensity of energy consumed through promotion of renewable energy production
- Placing a direct cost on carbon emissions via a carbon tax or carbon trading system

Energy efficiency improvements and renewable energy production are being driven through by both incentives and legislation while direct carbon emission reduction mechanisms tend to be purely driven by legislation.

2.0 Energy use in winemaking

2.1 Introduction

There are many different systems, spaces and processes required in the modern winemaking facility. Figure 2.1 schematically indicates some of the more common headings used to describe the activities associated with the production of wine. Each of these activities have a role within the modern winemaking facility and have a corresponding energy requirement, which collectively relates to an energy input necessary to produce the finished product.

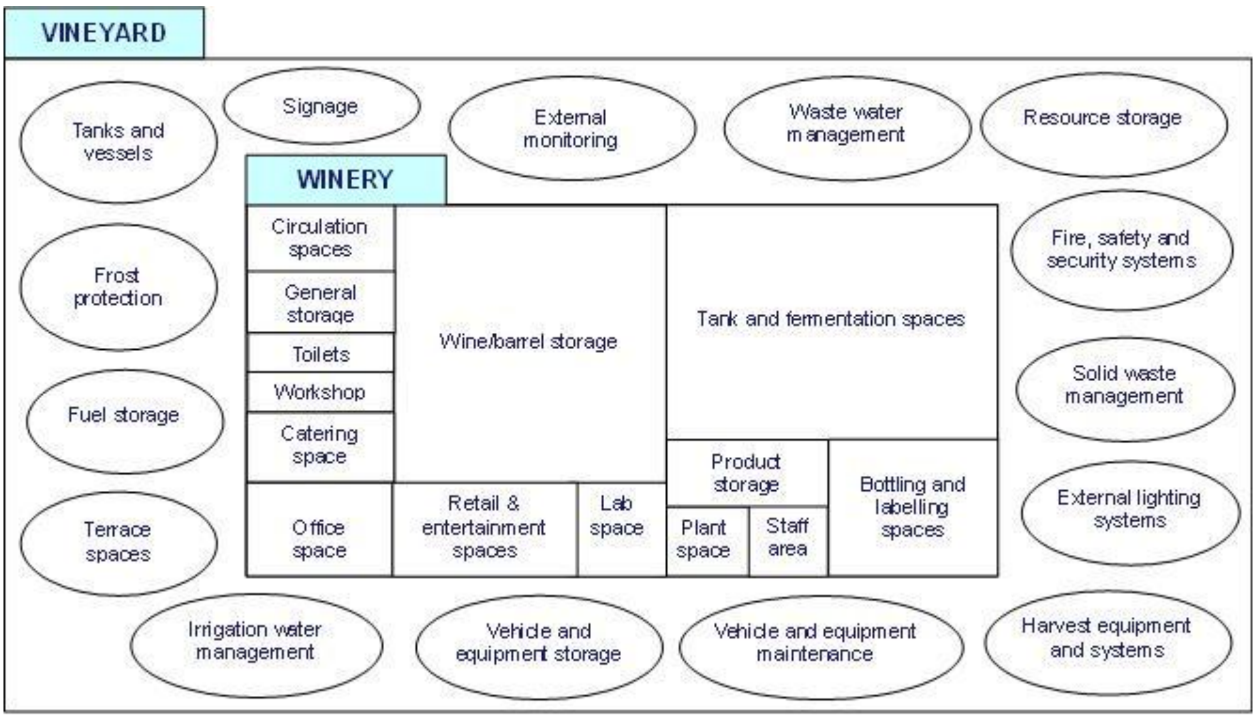


Figure 2.1: Schematic representation of winemaking requirements

To understand the process inputs and outputs that contribute to the energy use of a winemaking enterprise, one of the most effective methods is to map the supply chain so that all energy and fuel related inputs are accounted for. In simplistic terms this can be represented through vineyard and winery activities, as presented in figures 2.2 and 2.3, respectively.

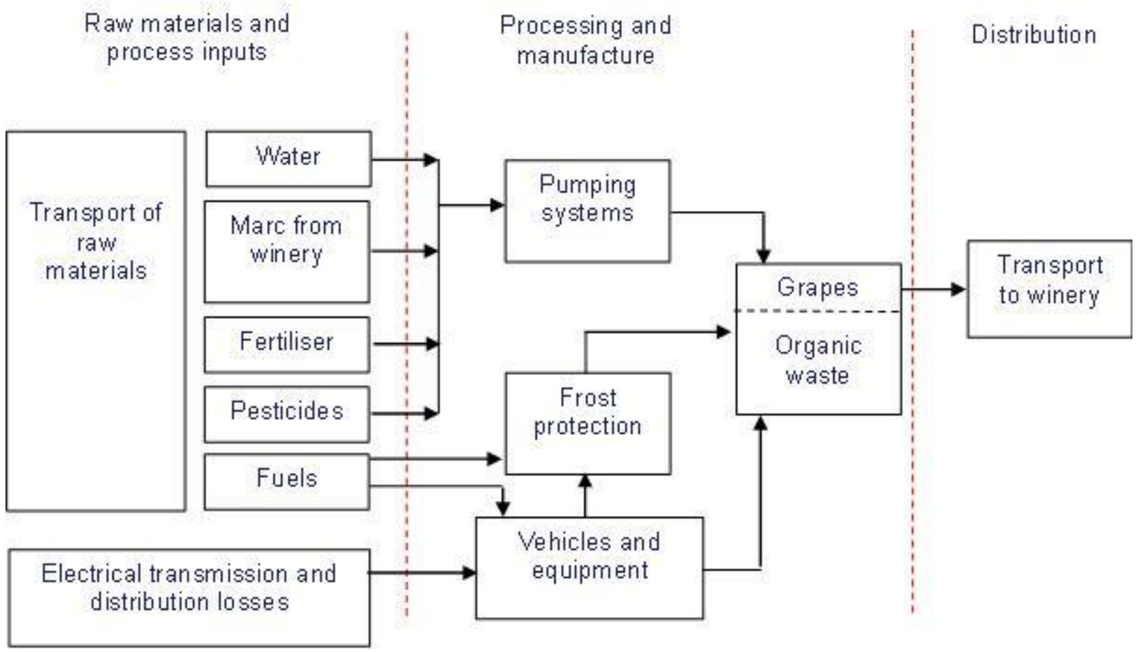


Figure 2.2: Vineyard supply chain showing fuel and energy inputs (adapted from Forsyth et al 2008)

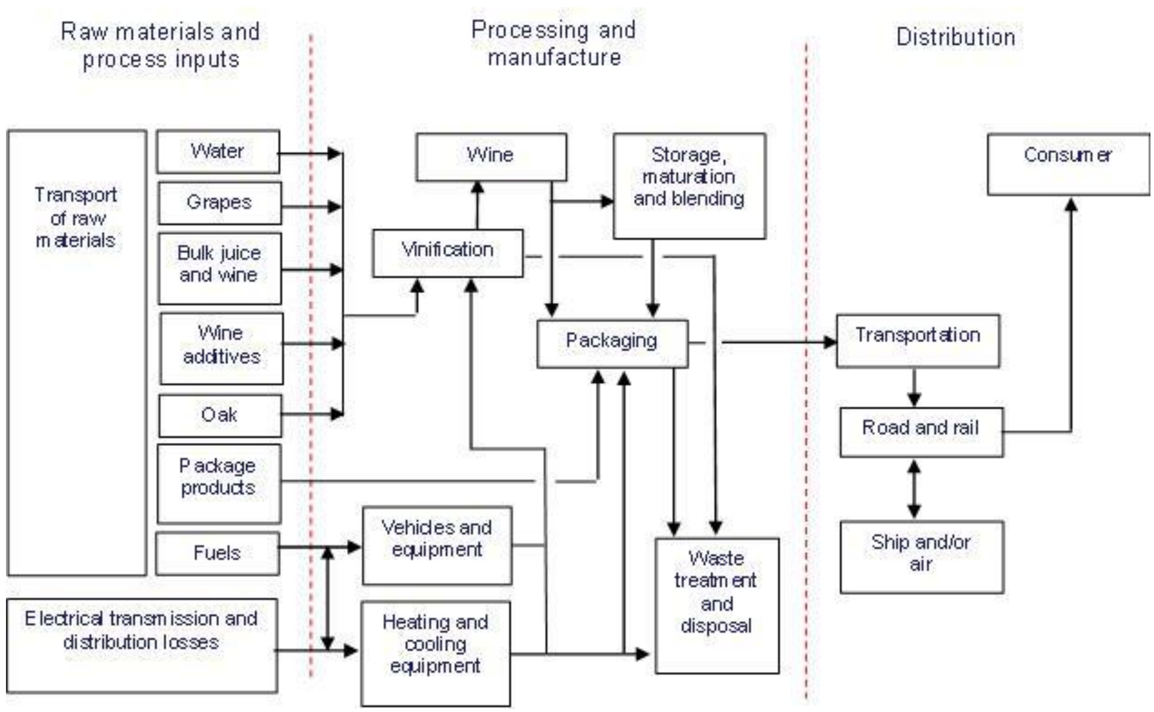


Figure 2.3: Winery supply chain showing fuel and energy inputs (adapted from Forsyth et al 2008)

English wine is predominantly Sparkling Wine (currently ~50% of production) or light aromatic wine wines. The shift over the last few years has been from growing older Germanic varietals to planting classic Champagne varieties: Pinot Noir, Pinot Meunier and Chardonnay to produce traditional method sparkling wine that rivals and tops some of the finest in the world. Some regional climates are also suitable for producing high-quality light, dry, floral and aromatic wines such as Pinot Gris and Bacchus. Small quantities of Red wine, including still Pinot Noir are also made as are some rose wines. Table 2.1 lists the top 10 grape varietal plantings in the UK in 2010 (English Wine Producers, 2012)

Grape Variety	Ha planted	% of total ha
Chardonnay	249.30	18.84
Pinot Noir	247.77	18.72
Bacchus	128.35	9.77
Seyval Blanc	92.99	7.02
Reichensteiner	85.38	6.45
Muller Thurgau	61.39	4.63
Pinot Meunier	52.58	3.97
Madeleine Angevine	47.03	3.55
Rondo (GM 6494/5)	44.91	3.39
Schonburger	42.03	3.17
Others	271.19	20.49
Total Hectarage recorded (all varieties)	1323.51	100

Table 2.1: Top 10 Grape Varietal Plantings in the UK 2010 (English Wine Producers, 2012)

As indicated in the previous figures, to accurately assess the absolute energy requirement of a commercial winemaking enterprise is quite a difficult task, due to the range and inter-relationship between variables, which includes highly variable parameters such as transportation to market or embodied energy. It is therefore more simplistic (and realistic) to determine the measurable indicators specific to each facility, namely the energy inputs that can be accounted for within the boundaries of the wine producing facility.

2.2 UK Winemaking study

The presented study of energy usage with the UK winemaking facilities (primarily English) was conducted during the summer months of 2012. The energy study was based upon a representative number of energy audits conducted at an individual winery level including a walk-through energy survey (visual inspection and information relating to installed equipment and operating processes) of the winemaking facility and (where possible) at least 3 years historic production figures, utility use and distribution. The survey did not include vineyard operations or energy usage. The wineries surveyed were representative of the geographic distribution of producers in the UK, with most existing in the South East, and southern England, and included a range of production scales from a few thousand bottles per year to over 300,000 bottles per year. Figure 2.4 presents a geographical distribution of the wineries surveyed.

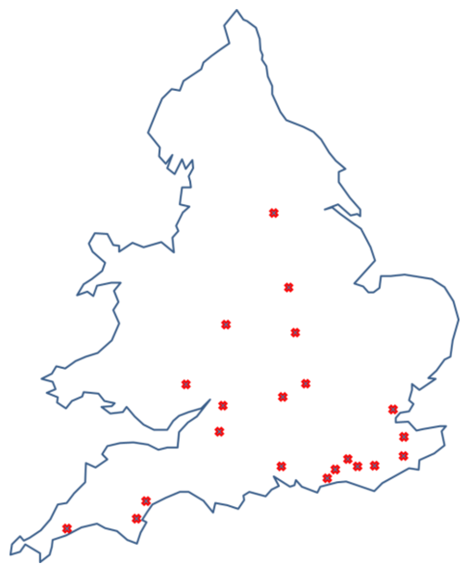


Figure 2.4: Geographical distribution of the wineries surveyed in study

A total of 21 commercial wineries participated in the survey, representing 17% of the total 124 commercial wineries in the UK (English Wine Producers, 2012). Seventeen wineries from the 21 wineries surveyed, had full annual datasets relating to the energy used and corresponding production output values. Figure 2.5 illustrates the bottle output and annual energy consumption from all winery activities. Based on the data collected from the study, the combined (average yearly) bottle production for the wineries surveyed was 1,032,194 bottles, equating to approximately 774,145 litres of wine. Compared with the 2010 UK harvest, which produced 30,346 hectolitres of wine, equating to just over 4 million bottles (English Wine Producers, 2011), this study represented almost 26% of the total wine production capacity in the UK. Previous studies have indicated that sparkling wine is the most widely produced wine style in the UK (English Wine Producers, 2011), representing approximately 50% of total production. This is broadly in line with the current study which identified 502,478 bottles (or 49%) to be sparkling wine and 529,716 bottles (or 51%) were still wine, collectively produced from five wineries which were exclusively sparkling wine production, 9 wineries which produced both sparking and still wine and 7 which produced still wine only. Nearly 37% of all the bottles produced came from a sparkling only producer, 60.6% came from a mixed sparking/still producer and only 2.4% came from a producer that produced still wine only.

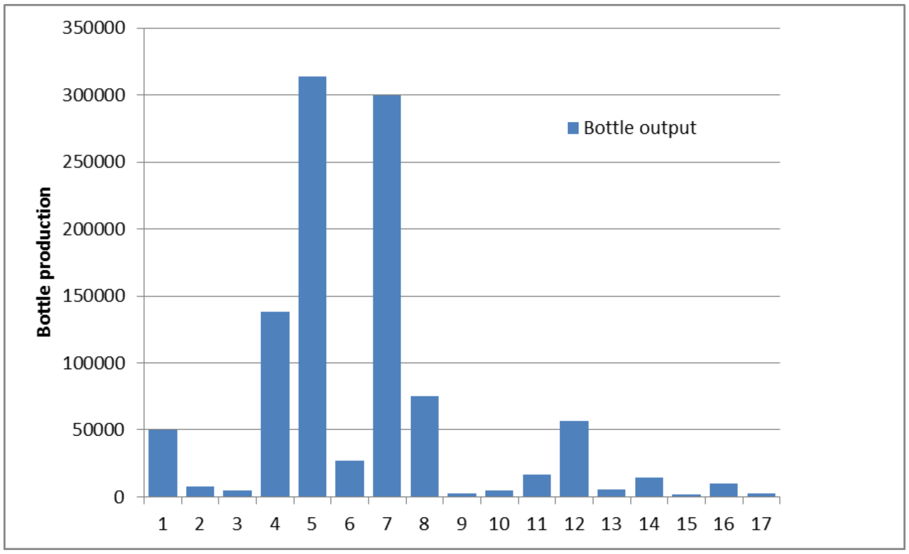
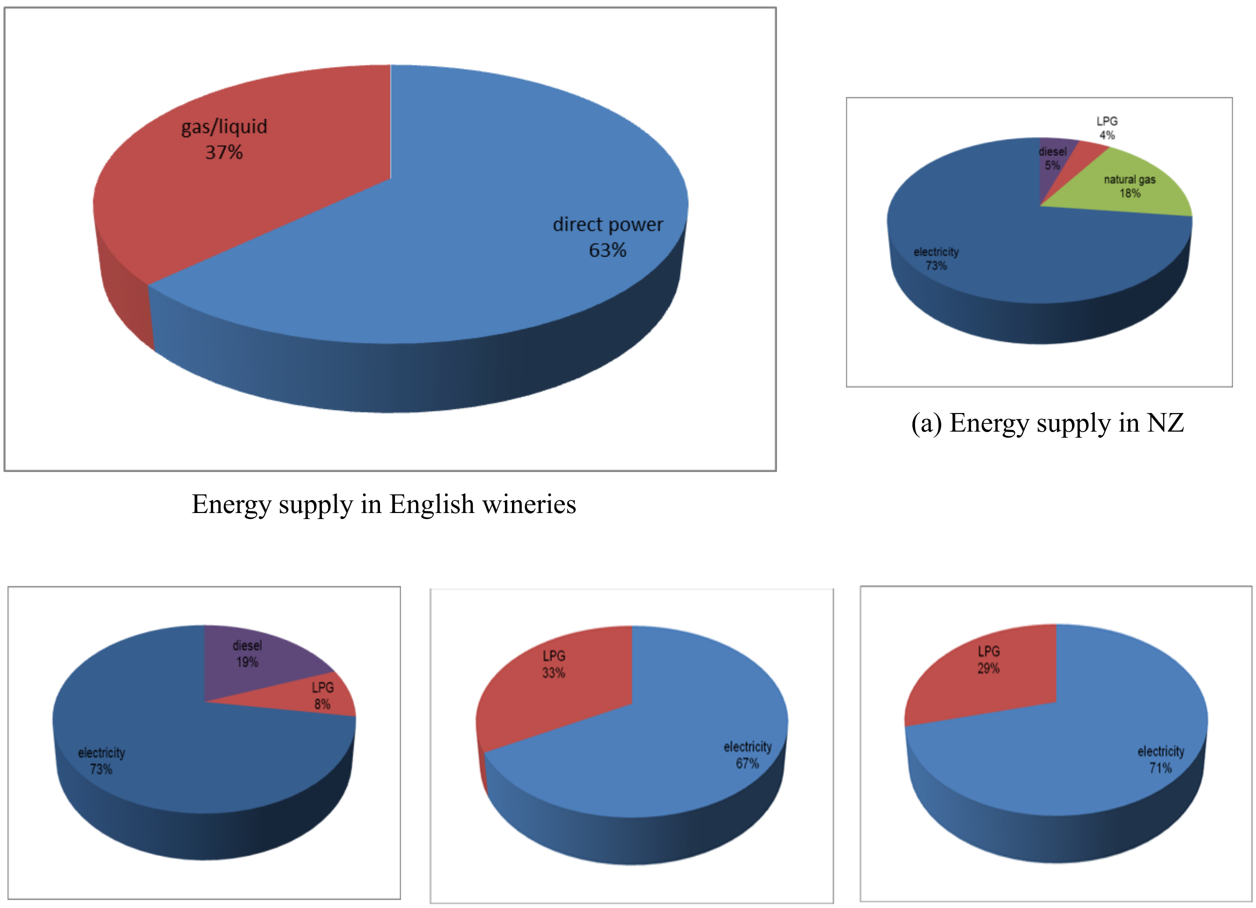


Figure 2.5: Combined (average yearly) bottle production for the wineries surveyed

2.3 Energy supply in the English winery

From previous studies conducted in other winemaking regions of the world (Van der Zijpp, 2008; Smyth, 2010; Anon, 2010a; Cotana and Cavalaglio, 2008), the dominant energy segment within the winery is electricity, with gaseous and liquid fossil fuels such as natural gas, LPG and fuel oil/diesel making up the remainder. Typically electricity constitutes between 65% and 75% with gaseous and liquid fuels making up the remainder. In the English winemaking industry (figure 2.6), approximately 62.9% of the energy used is supplied from a direct electrical supply (grid, PV, wind, etc.). Gaseous and liquid based fossil fuels account for the remaining 37.1%.



Energy supply in English wineries

(a) Energy supply in NZ

(d) Energy supply in Italy

(c) Energy supply in South Australia

(b) Energy supply in California

Figure 2.6: Comparison of the total annual energy supply breakdown in English wineries in comparison to other winemaking nations (a) NZ (Van der Zijpp 2008), (b) California (Smyth 2010), (c) South Australia (Anon 2010a), (d) Italy (Cotana and Cavalaglio 2008)

In studies conducted in other winemaking nations, the segmentation of energy supply is quite similar to that exhibited by the English wineries. In a study by Van der Zijpp (2008), encompassing almost half the wine producing facilities in New Zealand, electricity was accountable for almost three quarters of the energy requirement in the wineries. The energy distribution use in the Californian wineries study (Smyth 2010) illustrates that electricity was 71% of the energy used. In a specific study of a South Australian winery (Anon 2010a), the winery had a specific energy usage of 2.14 kWh per litre of wine produced, of which 67% was electrical power. Cotana and Cavalaglio (2008) studied the energy consumption of an Umbrian winery in Italy. The winery used diesel oil and LPG boilers for steam and heat production and electricity (73%) for the majority of all the other energy requirements.

From analysis of the surveyed English wineries, they tend to exhibit a slightly lower percentage of electrical power to liquid or gas sources due to a number of factors. The main factor is the proportion of refrigeration and space heating required. The UK climate is colder than most other wine producing regions and therefore there is a greater demand for space heating, primarily during the winter months but occasionally in the spring and autumn months. Likewise, the cooler ambient temperatures reduce the need for refrigeration (both comfort and winemaking processes), or at least the level of refrigeration required. Secondly, due to the scattered, rural nature of many English vineyard/wineries, many wineries have either no direct electrical power supply or there is no 3 phase electrical supply available and therefore rely on an on-site (fossil fuelled) electrical generator to produce power. Even though the actual energy demand was electrical, a kWh ratio of typically 3:1or 4:1 from the liquid fossil fuel calorific value was necessary to produce the electricity; the rest being lost as heat in the generator.

2.3.1 Liquid fuels used in the English winery

Within English wineries, liquid fuels such as diesel, heating oils and kerosene (35 and 28 sec), and petrol are used in a variety of uses, primarily in boilers for hot water production (domestic and process sanitation or space heating), on site power generation or by power washing units. Just over 21% of all the wineries surveyed used heating oil within the winery, primarily for space and water heating. Figure 2.7 illustrates some of the common uses for liquid fuels.

Figure 2.7: Examples of liquid fuel usage in the winery (power washer and diesel/petrol generators)

2.3.2 Gaseous fuels used in the English winery

Gaseous fuels used in the English wine industry include natural gas, Liquid Petroleum Gas (LPG) and propane. Whilst some of the gaseous fuels used in the winery are attributed to transportation (fork trucks), a significant proportion is used in heating processes, particularly space and water heating with some for cooking and food preparation (figure 2.8). Almost 26.3% of the English wineries surveyed used a gaseous fuel, primarily LPG in tank or bottled form (figure 2.9).


Figure 2.8: Examples of gas fuel usage in the winery (gas fired portable heater; gas fork truck, domestic hot water)


Figure 2.9: Examples of gas fuel storage/supply

2.3.3 Electricity used in the winery

It is evident from the study of English wineries that there is a great diversity of energy sources used by the wineries to provide electricity used in the winery. The vast majority of wineries have a 3 phase (Ø) electrical grid connection (63%). However, the need for a 3Ø electrical supply within the production facilities has driven a number of producers to have an on-site generator capable of producing 3Ø electrical power or a power converter to produce 3Ø power from a single phase grid supply. Table 2.1 details the breakdown of power sources from the 21 wineries surveyed.

Power supply format	3Ø grid	1Ø grid only	site generator	3Ø conversion	wind	PV
Percentage (%)	63.1	26.3	21.1	10.5	10.5	36.8

Table 2.2: Winery power supply sources

Over a fifth of the wineries surveyed required some form of fossil fuel generator to produce either a single phase or three phase power supply. The primary reason for this was based on the remote location of the winery and/or the cost of getting an electrical supply connected. Nearly 10% of the wineries surveyed used power converters (figure 2.10) to convert a single phase supply to a three phase power supply. This is common for many rural businesses or farm properties that do not have access to a 3 phase supply or may not want to pay for the extra cost of installing a 3 phase line supply. However, most of the significant equipment in a moderately sized winery will use three phase equipment (grape press, pumps, bottling equipment, etc) and therefore it is a necessity to have access to three phase electricity. There are two main types of single phase to three phase converters used; Rotary Phase Converters and Static Phase Converters. The majority of power convertors recorded by the current study were rotary phase converters.

Figure 2.10: Examples of phase convertors used in English wineries

One winery used a PTO or power take off generator to supply 3 phase power to the winery (figure 2.11). The PTO generator was coupled directly to the tractor PTO shaft with the tractor shaft providing the driving force to propel the alternator within the generator. The winery used the PTO for powering the press, transfer pump and tank agitator only.

Figure 2.11: Examples of power take off generator coupled to a tractor in an English winery

2.3.4 Renewable energy used in the English winery

A significant number of wineries utilised renewable technologies. Wind energy in the form of small wind turbines (figure 2.12), was installed in 10.5% of the surveyed wineries (Sizes). Solar PV was the most popular renewable technology, perhaps due to the ease of installation/maintenance, electrical load matching and attractive financial incentives. Nearly 37% of the surveyed wineries had some form of PV installation installed. Most of the installations are relatively small by commercial standards, but are sufficient to provide a useful amount of power to the winery during midday conditions. Figure 2.11 depicts a small (Sizes). The majority of the installations convert generated DC solar PV power directly into AC power via the installation's inverters for direct integration into the building grid or export to the electricity providers supply grid (figure 2.14). One producer utilised DC battery storage to store 'solar power' before conversion to AC electricity for winery use (figure 2.15).

Figure 2.12: Examples of winery wine power

Figure 2.13: Examples of roof mounted PV installations

Figure 2.14: PV system inverters (direct building grid supply)

Figure 2.15: PV system inverter with battery storage

One winery had a solar thermal system (evacuated tube) installed, primarily used for domestic hot water needs related to retail and administrative requirements and less with production needs. Two wineries had wood burning bio-mass installations; one used stand-alone stoves whilst the other used a burner/boiler to provide hot water to the radiators in the buildings LTHW central heating installation (figure 2.16).

Figure 2.16: Example of a roof mounted solar thermal installation and integral bio-mass burner/boiler

2.4 Energy use in the English winery

The modern winery can produce a wide range of different wine products, from dry sparkling to sweet dessert wines. However, the vast majority of wines fall under the heading of sparkling or still red, rose and white wines. This is exactly the case in English wine making with a more or less even split between sparkling and still wine with significantly more white still wine produced compared to rose or red wine.

Energy use within the English wineries surveyed is described as either energy expended in wine production or energy expended in ancillary support services. Energy used in production describes all the energy expended by the processes and equipment necessary to produce the final product and covers everything from the arrival of the grapes at the winery door to the finished, packaged product leaving the facility. Ancillary support services relates to all the energy expended in the retail and administrative functions necessary to facilitate the winemaking process and includes wine tasting and sales, sanitation, food preparation, office and staff areas. The total winemaking energy use presented in this study is the combined value of energy expended in production and ancillary requirements for any given winery. This study did not cover the energy used in vineyard activities, product transportation, accommodation and other separate product processes conducted on the site such as beer, cider or cheese production.

The vast majority of the energy used in the winery is related to production. From the information gathered from the commercial wineries participating in this the survey, 512,350 kWhs of energy was expended to produce a total of 1,032,194 bottles of wine in an averaged year. Just over 431,226 kWhs (or 84%) was used in production with the remaining 81,124 kWhs related to ancillary support service requirements.

To enable an accurate representation of where energy was used with the winemaking facilities, an outline of energy categories was created. In this study production energy requirements were broadly categorised as being:

- Lighting: includes all energy associated with the lighting of the production/storage areas of the winery
- Grape processing: includes all equipment and processes involved in the receiving, crushing and pressing of grapes and any compressed air energy requirements
- Juice/wine pumping, filtration and mixing: includes all energy expended in the transfer of juice/wine from the press, tank to tank transfers, tank to bottling, filtration and mixing activities
- Bottling: includes wine filling, crown capping and disgorging, corking, wiring, foiling and labelling, packaging and compressed air energy requirements
- Thermal conditioning: includes all space and process heating, cooling and ventilation requirements, Low Temperature Hot Water (LTHW) and chilled water production and covers the energy used by refrigeration plant, Air Handling Units (AHUs), terminal units, fans and associated pumps and control devices
- Sterilisation and cleaning: includes equipment used in hot water and steam production, associated pumping and power washers
- Winery moving machinery: primarily fork trucks (gas, diesel, electric) but also includes

electric trolleys and lifts
- Miscellaneous: a very broad category that includes a range of equipment necessary to provide a suitable working environment for the production processes and includes monitoring devices, security devices, shutter doors, insect control and laboratory equipment

Just over 57% of the surveyed wineries had separate administrative areas and dedicated wine tasting and retail areas open to the public. In this study, nearly 16% of the total annual energy used by the wineries was related to ancillary support service requirements. Ancillary support service energy requirements were broadly categorised as being:

- Lighting: includes all energy associated with the lighting of the retail, office and staff areas
- Thermal conditioning: includes all space heating, cooling and ventilation requirements
- Sterilisation and cleaning: includes all energy requirements used in sanitation activities
- Miscellaneous: a very broad category that includes PC, laptops and general office equipment (printers, fax machines, Wi-Fi and routers, telephones, laminators, shredders, photocopier), audio-visual equipment, cash registers, credit card readers, hand dryers, microwaves, bottle coolers and dishwashers.

The English wine industry is not a homogenous industry. This study highlighted the disparity between the various wineries and winemaking facilities and practices currently being used. All the wineries visited were more or less rural in a location which in itself led to interesting issues relating to utility connection (power, gas and sanitation), often resulting in a stand-alone operation. Just on size, there was a wide variation; the largest winery producing on average 313,771 bottles per year to the smallest producing just1,500 bottles in the same time period. All the wineries surveyed operated commercially, but could be broadly classified as being either small cottage concerns, family run businesses or large commercial companies. Due to the recent surge in English winemaking, a number of the wineries were relatively new, being in production for perhaps a few years. Likewise, an equal number of wineries had a long established name in the industry. Many wineries offered other parallel services by providing accommodation or having a restaurant or cafe or producing other products such as beer, cider or cheese. In addition to the wide range of wine produced by individual wineries, several wineries offered contract services to some of the smaller or less specialist wineries, in particular sparkling wine production services.

There was a wide distribution in the winery building types and range of equipment used within the various wineries. Most wineries were housed within one building, although almost a quarter of the wineries surveyed consisted of a number of separate buildings, scattered over the production area. A number of wineries were new, purpose built, state-of-the-art winery buildings, designed with winemaking practices to the fore, including dedicated wine storage cellars or grape receiving stations. However, many of the wineries visited were created by refurbishing existing buildings (primarily farm buildings) or adapting existing spaces. Likewise, the level (and age) of equipment and process automation differed significantly, from fully automated winemaking facilities (with little human intervention apart from the moving of wine/bottles from station to station) to the more common partially automated or manual with significant mechanical input through to some wineries that were entirely manual in operation.

Of course all of these differences had a big impact on the energy expenditure by anyone winery and this is related in the variation in the stated energy usage and benchmarking values within this study. The impact and lessons for energy efficiency are discussed in a later chapter. The following sections detail the typical energy flow processes exhibited by most modern (medium sized) wine making facilities and the energy flow processes common in English winemaking activities.

2.4.1 Energy process flow for sparkling wines

There are four main methods of producing sparkling wine, each having a very different energy requirement. The main methods are listed as:

- Carbon dioxide (CO_2) injection where CO_2 is injected directly into the bottled wine
- ‘Charmat’ where the wine undergoes the secondary fermentation in a bulk tank and is bottled under pressure
- ‘Traditional method’ or ‘méthode champenoise’ where the secondary fermentation takes place in the bottle. As the name indicates, this method is used in the production of Champagne and is more energy intensive than the previous two methods
- ‘Transfer method’ is similar to the ‘traditional method’ but following secondary bottle fermentation, the wine is transferred back into a pressurised tank again before bottling

Producing sparkling wines by the ‘méthode champenoise’ or ‘transfer method’ in the modern winery requires a significant amount of automation and energy input. Figure 2.17 illustrates the typical process diagram for ‘méthode champenoise’ and indicates the various energy inputs into the production line. In the English wineries surveyed, nearly all the sparkling wine producers used this method of production, either in-house or indirectly via a contract winery.

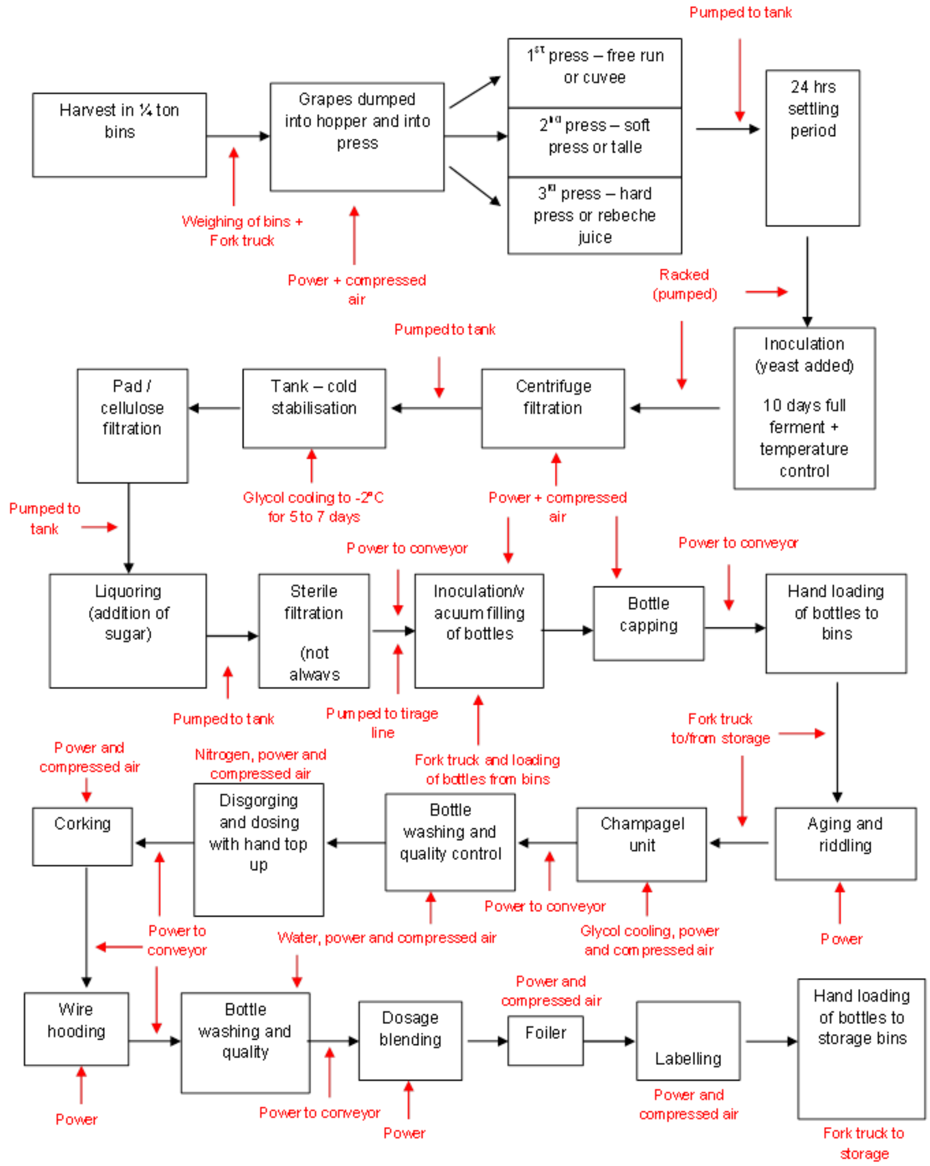


Figure 2.17: Typical energy flow process diagram for 'méthode champenoise' sparkling wine

2.4.2 Energy process flow for still wines

The energy required in the process stages for producing still wines differs significantly from that used in sparkling wine production. All still wine energy requirements can be broadly grouped together, however there are a number of differences in the production of red or white styles. Whilst it is difficult to demonstrate all the variations used in making the wide range of wine styles in this category, figures 2.18 and 2.19 detail a very generic form of still wine production (red and white, respectively) and the commonly applied energy inputs.

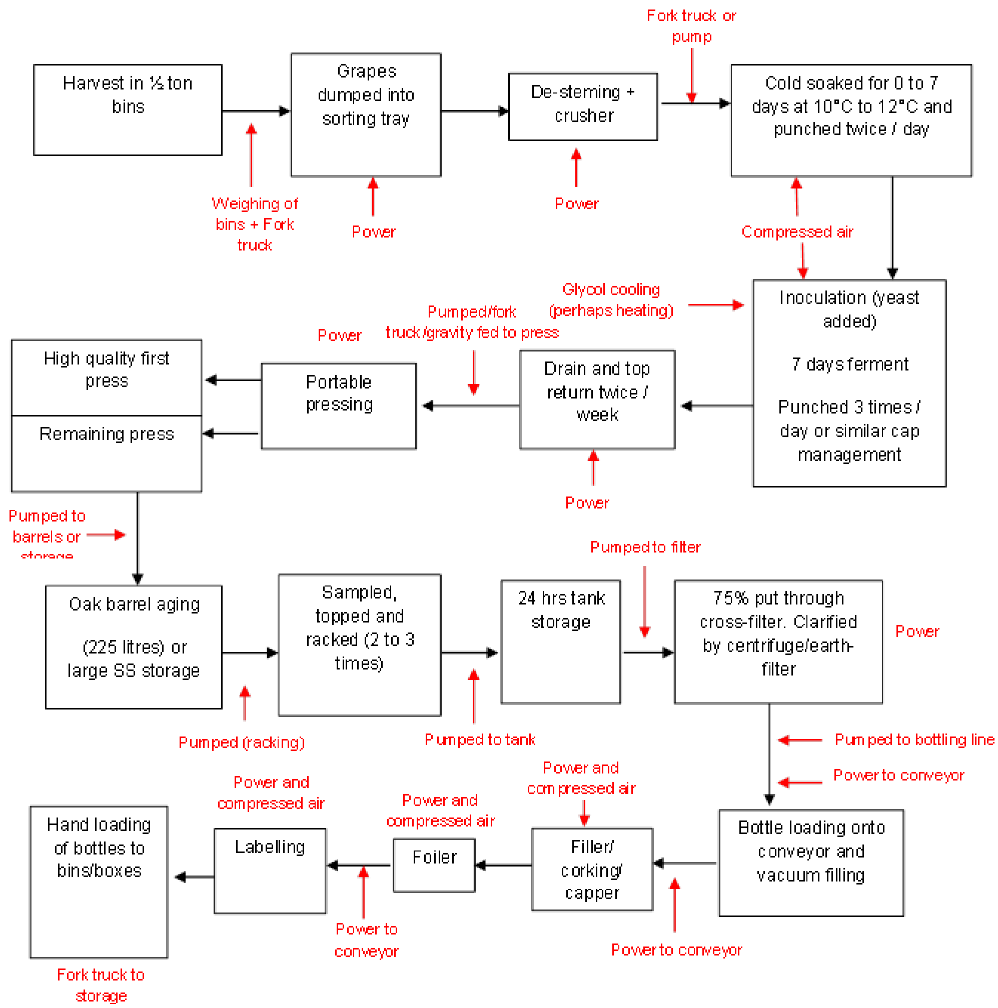


Figure 2.18: Typical fully 'automated' energy flow processing diagram for still red wine

Of all the service requirements in the still wine production process, electricity is by far the largest energy input. Physical handling of the product, both into the process line and from the process line, is mostly via electric or gas fork truck vehicles. Significant amounts of compressed air is required, primarily for pressing, punching and various activities in the bottling line and some heat via combustion equipment may be necessary in certain circumstances. Electricity is used throughout the process for the major chilling, pumping and mechanical activities.

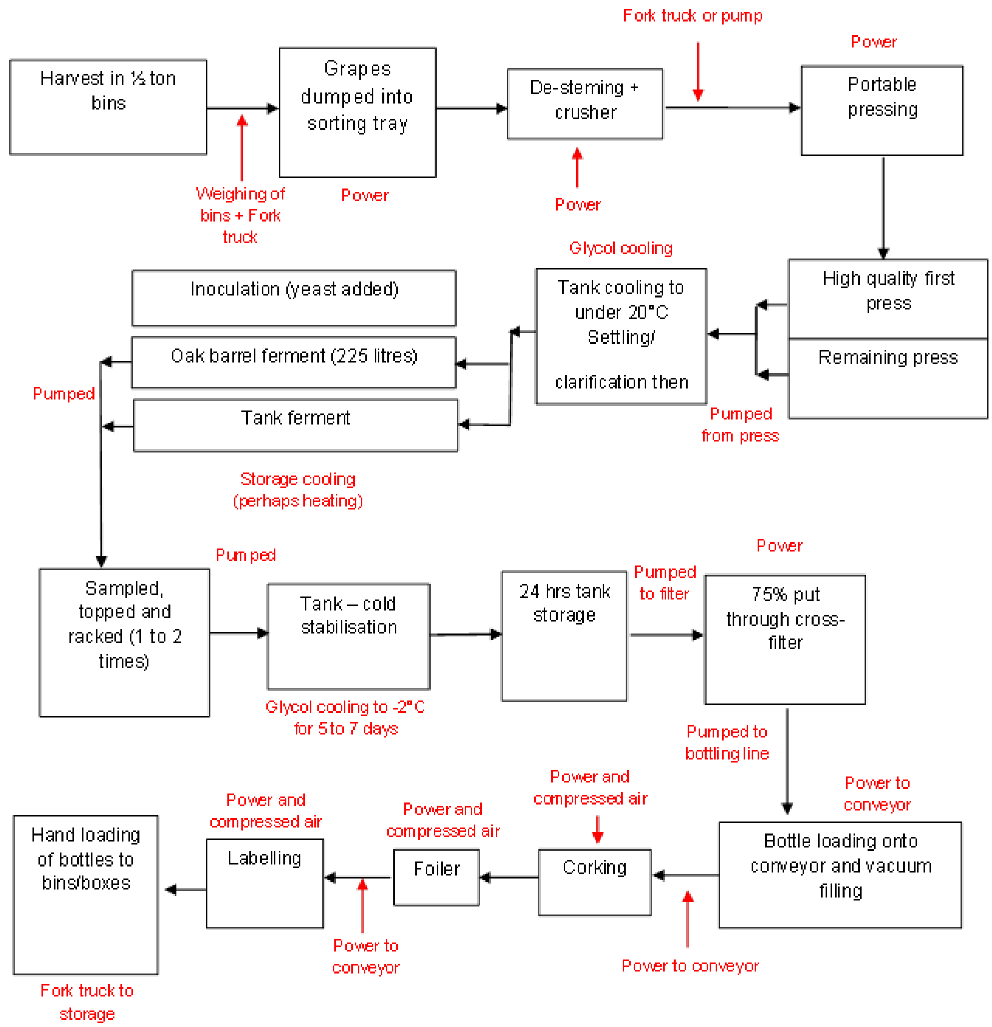


Figure 2.19: Typical fully 'automated' energy flow processing diagram for still white wine

2.4.3 Analysis of energy expended in English wine production

Of the 21 wineries surveyed, only 17 wineries had a full annual datasets relating to the energy used in the winery and the total production values available for this investigation. Figure 2.20 illustrates the bottle output and annual energy consumption from all winery activities. Figure 2.21 illustrates the bottle output and annual energy consumption from all winery production activities. Based on the data collected from the study, the combined (average yearly) bottle production for the wineries surveyed was 1,032,194 bottles, equating to approximately 774,145 litres of wine.

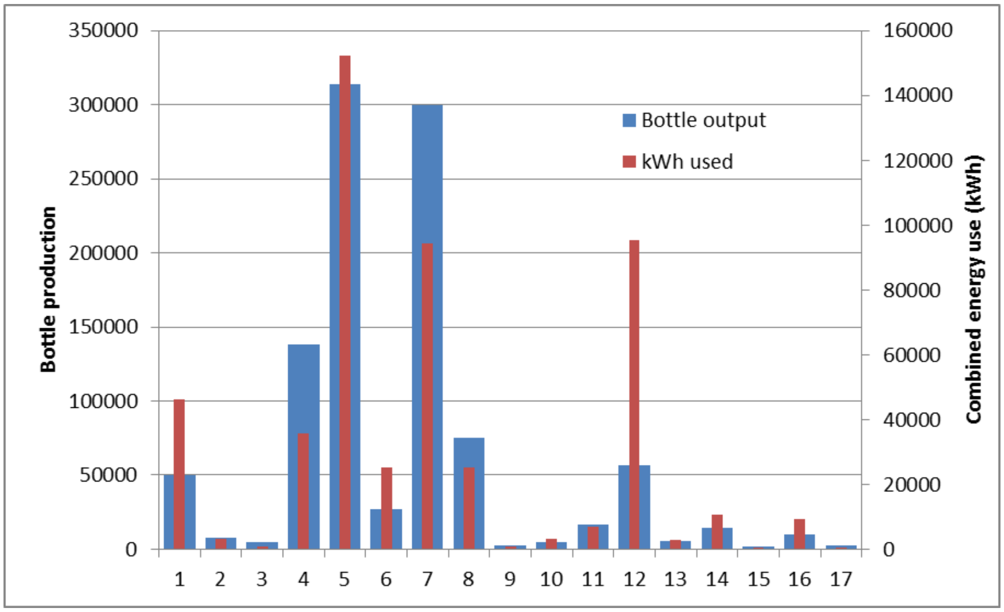


Figure 2.20: Bottle output versus total energy expended by 17 English wineries

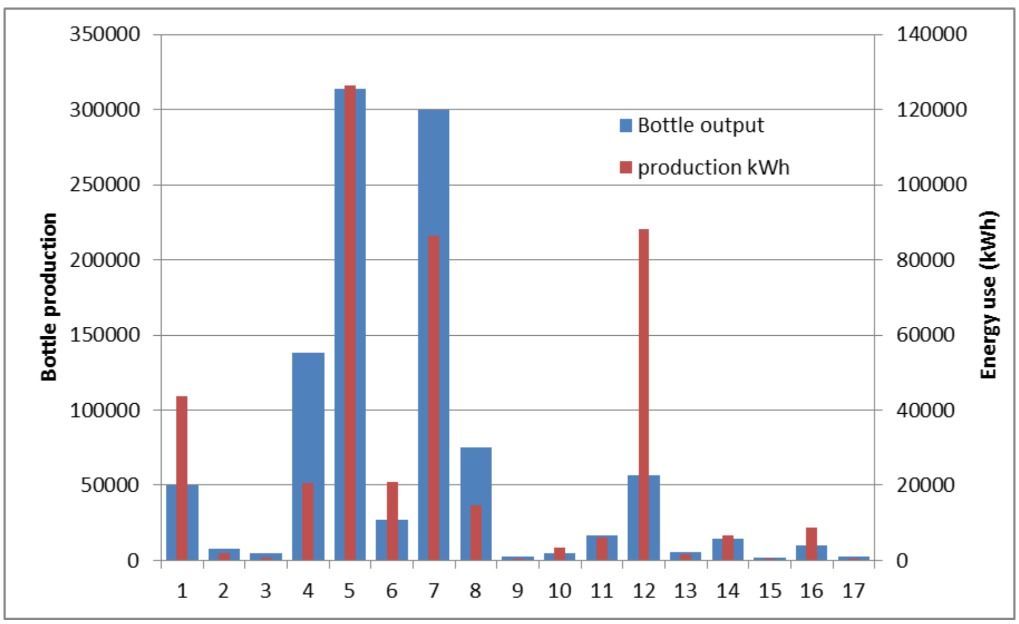


Figure 2.21: Bottle output versus total energy expended in actual wine production for 17 English wineries

Figures 2.20 and 2.21 illustrate the bottle output and annual energy consumption from all winery activities and production activities, respectively. A total of 512,350 kWhs of energy was expended to produce a total of 1,032,194 bottles of wine in an averaged year from the surveyed wineries, of which 431,226 kWhs was necessary for production. As expected, there is a big variation from winery to winery, with some wineries requiring significantly more energy in relation to the production output. The reasons for the variety are many but are primarily dependant on the equipment or processes used, the winery size and style of wine produced.

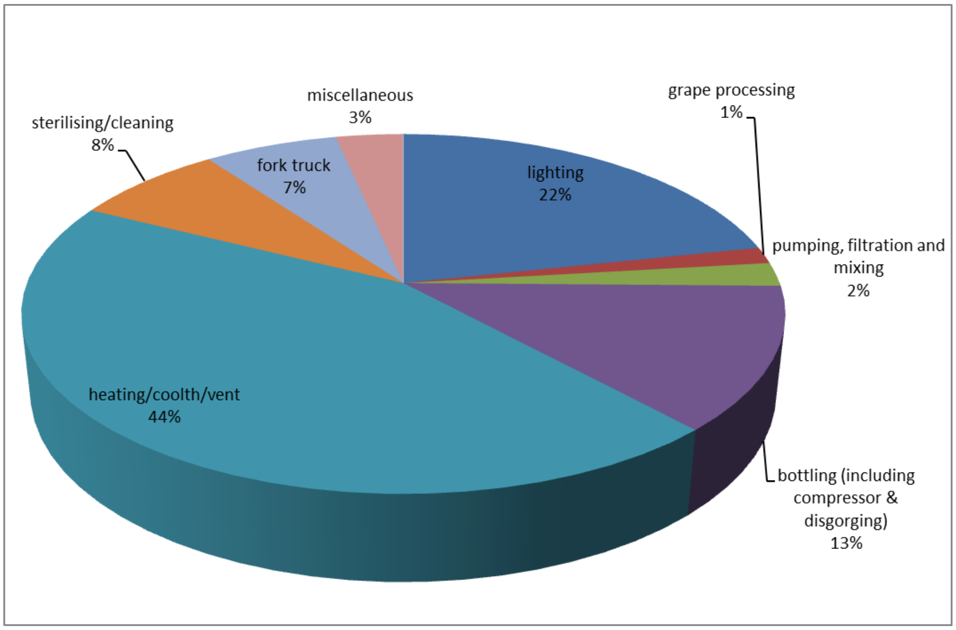


Figure 2.22: Distribution of energy expended in production for all the English wineries investigated

Figure 2.22 illustrates the distribution of energy expended in the production activities in all the English wineries investigated. Heating, cooling and ventilation are by far the biggest segment (44%) of energy use within the winery and therefore represent the area where the greatest energy savings could be made. The vast majority of this activity is made up from water chilling operations by a relatively small amount of large winemaking facilities. Bottling activities (at 8%) reflects the use of significant mechanical power via the automated bottling machinery or lines, some refrigeration in the disgorging process and the generally inefficient use of compressed air systems. Lighting, at 22%, is the second largest area of energy usage with the winery. This is primarily due to the extensive use of inefficient lighting systems being used for prolonged periods of operation. Again, lighting and an activity, represents an area which should be targeted to yield improvements in energy performance. Fork trucks and sterilisation/cleaning activities require a similar level of energy input.

In relative terms, grape processing and pumping (and associated activities) are very small segments of energy use within the winery. There are often the most visible activities of any winery and are certainly synonymous with the winemaking process. From a kW power requirement, much of the equipment may be the largest in the winery but from a kWh usage of time, it may be one of the smallest. For example, a Coquard PAI8000 sparkling wine press using a hydraulic ram and gentle horizontal movement to break the press cake has a power rating of 10kW. However, based on a typical 3 hour press cycle, the entire unit only uses 3 kWhs of energy (Coquard Presses, 2012).

Figure 2.23: Grape processing equipment representing a high kW power rating but relatively low kWh energy usage

Winery size (or rather production output) has a significant impact on energy usage. In this study 4 wineries were categorised as large (greater than 50,000 bottles), 6 wineries as medium (10,000 to 50,000 bottles) and 7 wineries as small (less than 10,000 bottles). Figure 2.24 illustrates the distribution of energy expended in the production activities in all the English wineries by production output.

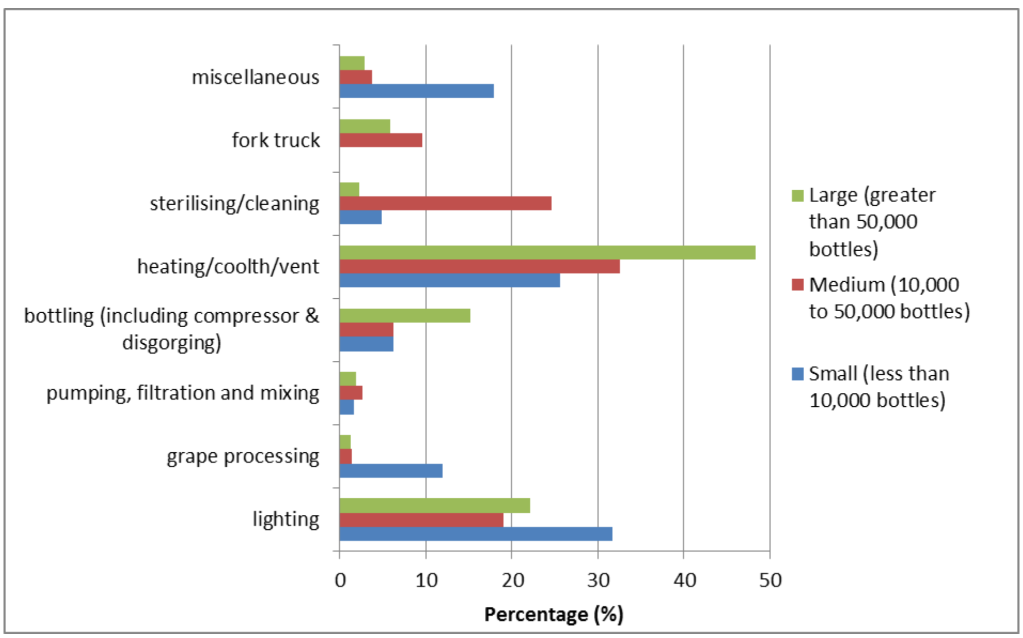


Figure 2.24: Distribution of energy expended in production for large, medium and small English wineries (Large (greater than 50,000 bottles); Medium (10,000 to 50,000 bottles); Small (less than 10,000 bottles))

The reducing energy requirement for heating, cooling and ventilation is evident as the winery reduces in size (from 48% to 25%). Likewise, the proportion of other activities is seen to increase for small wineries (lighting, grape processing and miscellaneous). No small wineries had the capital to invest in dedicated fork trucks.

The style of wine produced by a winery has also a large impact on the energy use and figure 2.25 presents some interesting patterns. In this study 4 wineries where sparkling only, 8 wineries where mixed sparkling and still and 5 wineries where still only. Sterilisation and bottling activities (due to the greater number of individual processes) are significantly greater in sparkling only wineries. Heating, cooling and ventilation requirements are similar for sparkling and mixed sparkling/still production facilities due to the need for more refrigeration. Still wine production facilities in proportion, therefore use more energy in lighting, grape processing and pumping activities.

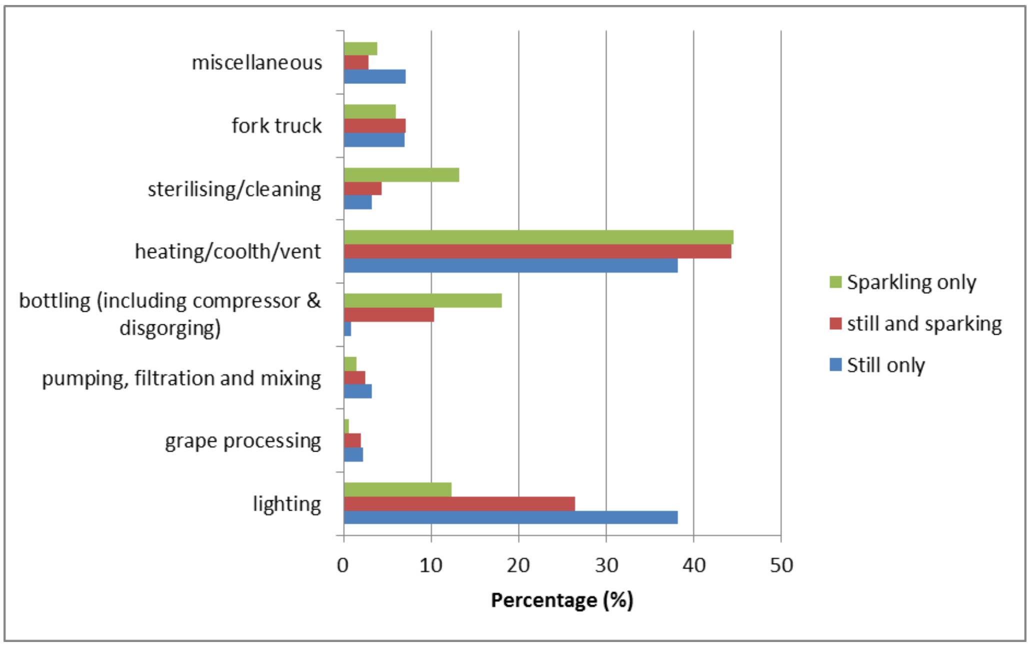


Figure 2.25: Distribution of energy expended in production by wine style (Sparkling only, mixed sparkling and still, still only)

Extrapolating the energy measured and reported in this study versus production output, the total annual energy expended by the English wine industry in making wine (in the winery) can be estimated. From the surveyed wineries, 512,350 kWhs of energy was expended to produce a total of 1,032,194 bottles of wine in an averaged year, equating to approximately 774,145 litres of wine. Compared with the 2010 UK harvest, which produced 30,346 hectolitres of wine, equating to just over 4 million bottles (English Wine Producers, 2011), 3,034,600 litres would equal 2,008,380 kWhs or 2,008 MWhs, which is equivalent to the energy released by burning 1181 barrels of crude oil (based on a barrel of oil equivalent (BOE)). In very rough terms, this is equal to the annual energy use (10 MWh thermal and electric) of 200 households in the UK per year.

From this value, 62.9% of the energy used is supplied from a direct electrical supply (grid, PV, wind, etc.) whilst gaseous and liquid based fossil fuels account for the remaining 37.1%. Based on DEFRA's Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme (DEFRA 2003), the UK electricity mix is equivalent to 0.43 tCO_2/MWh, heating oil is 0.27 tCO_2/MWh and LPG is 0.25 tCO_2/MWh. This gives a total headline value of 736.8 tonnes of CO_2 per year coming directly from English winemaking (1263 MWhs from power equating to 543.1 tCO_2 and 745 MWhs from fossil fuels equating to193.7 tCO_2). This headline value is equal to travelling 2,211,137 miles in a family sized car (DEFRA 2003).

Quantifying and reviewing the energy used within individual wineries is relatively easy, drawing comparisons across a number of wineries with many different variables to consider makes the task of analysis much more difficult. To permit an analysis of the data collated in this study, energy benchmarking was used.

2.5 Energy benchmarking

Energy benchmarking is a mechanism that allows a facility (winery) to compare and contrast the energy operating performance of individual plant and services or an entire process, or even a full facility against a common metric that represents ‘standard or optimal’ performance. In the wine industry there are a number of energy metrics available, but the more commonly applied metrics are based on a standard energy unit, typically the kWh, against a volume, weight or area. In Europe this is typically represented by kWh/litre of wine produced, kWh/m^2 of winery floor area or kWh/per tonne of grapes processes/crushed.

Benchmarking, done properly, is a tool that allows the winery management to evaluate and compare their systems, processes and plant against the accepted benchmark values, providing a means whereby the winery can analyse their own energy consumption trends and patterns and instigate or follow improvements in energy usage.

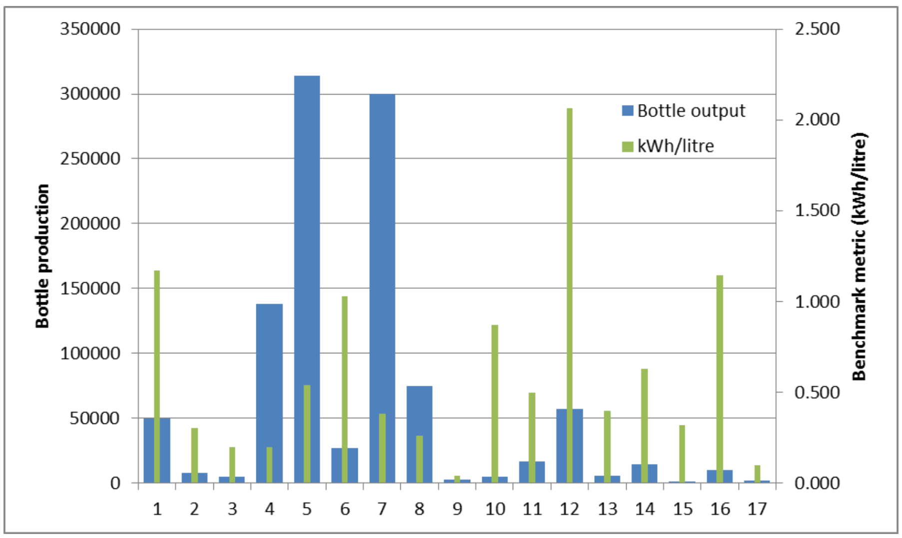


Figure 2.26: Bottle output versus production benchmark value (kWh/litre) for 17 English wineries

Figure 2.26 presents a range of kWh/litre benchmark for production only from individual English wineries. What is apparent is that the individual benchmark values differ depending upon many variables; location, winery age, wine style and quality, facility size and production output. The average production benchmark is 0.557 kWh/litre, ranging from 0.040 kWh/litre to 2.065 kWh/litre. As expected, the increased energy requirement in making sparkling wine is reflected in the benchmark values. Of the wineries surveyed that were exclusive sparkling wine producers, the calculated production benchmark was 0.86 kWh/litre, this dropped to 0.57 kWh/litre for mixed sparking/still production and down to 0.42 kWh/litre for still only production.

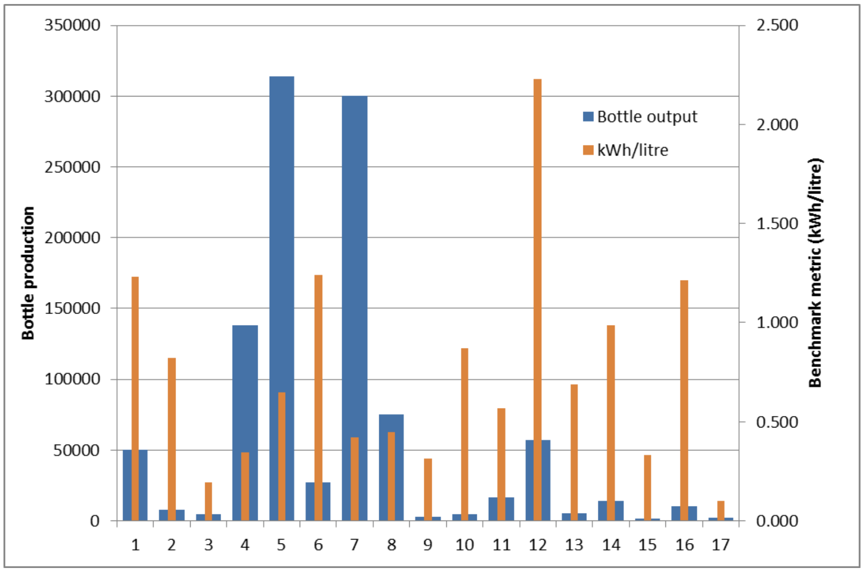


Figure 2.27: Bottle output versus total benchmark value (kWh/litre) for 17 English wineries

The benchmark value is equally variable when the total energy requirement is investigated (figure 2.27). The average total benchmark is 0.662 kWh/litre, ranging from 0.098 kWh/litre to 2.239 kWh/litre. The additional energy attributed to the retail and administrative requirements is only 0.105 kWh/litre.

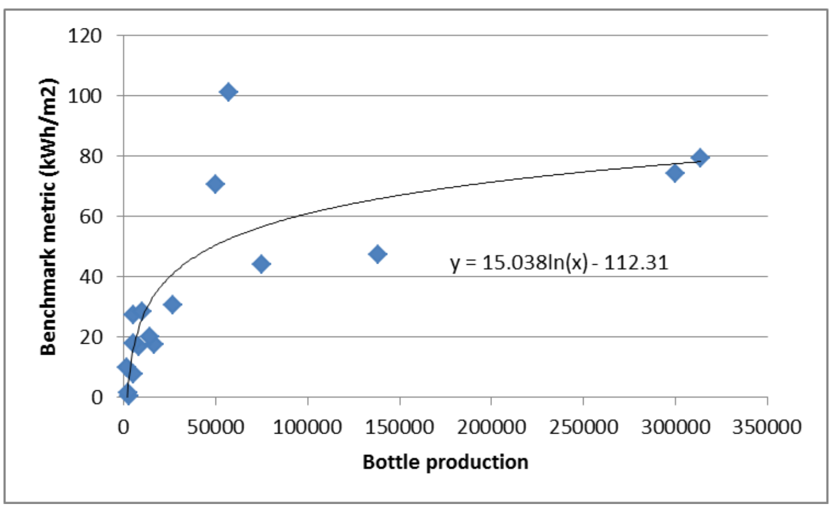


Figure 2.28: Bottle output plotted against production energy use per winery floor area (kWh/m^2) for 17 English wineries

There are too many variables to consider any correlation relevant between the various wineries surveyed in this sample based on the kWh/litre benchmark. However, when a kWh/m^2 benchmark is considered, a clearer correlation develops between production output, energy and winery size. From figure 2.28, the average upper benchmark value for a medium or greater sized winery (more than 300,000 bottles per year) is approximately 80 kWh/m^2. The average production benchmark is 34.92 kWh/m^2 and the value for the average total energy expended in the winery is 39.41 kWh/m^2. The distribution of values ranges from 0.043 kWh/m^2 to 100.9 kWh/m^2 for individual wineries.

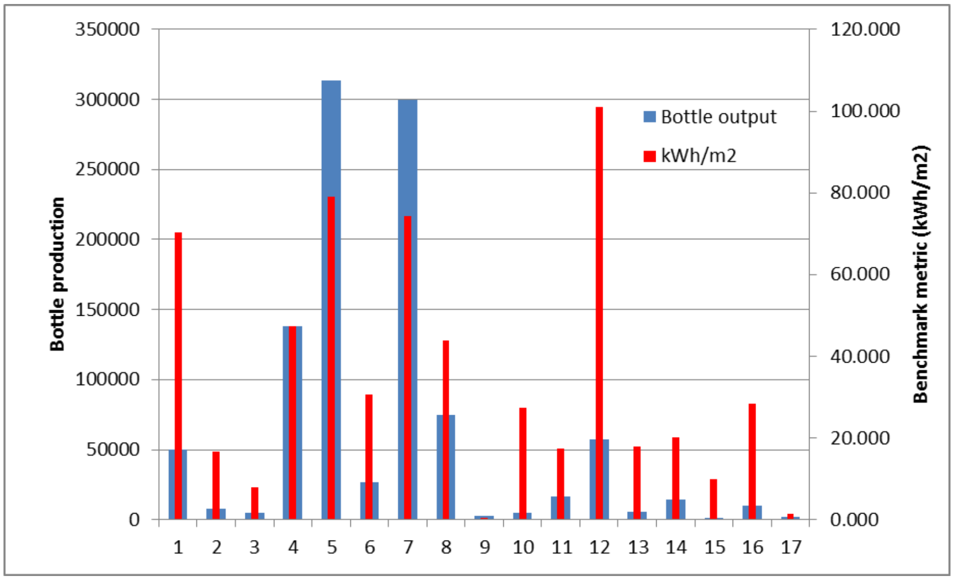


Figure 2.29: Bottle output versus production benchmark value (kWh/m^2) for various English wineries

	kWh/litre	**kWh/m^2**
New Zealand average	0.47 kWh/litre	/
The Mission winery, NZ	0.2 kWh/litre	/
Canadian range	0.21 to 1.9 kWh/litre	/
Nova Scotia average	0.7 kWh/litre	/
Australian range	0.75 to 2.0 kWh/litre	/
South Australian average	2.14 kWh/litre	/
Ferngrove winery, WA	0.25 kWh/litre	/
Domain Carneros, California	1.62 kWh/litre	190.7 kWh/m^2
Umbrian winery	/	122 kWh/m^2
English average	**0.557 kWh/litre**	**34.92 kWh/m^2**

Table 2.3: Various regional/National energy benchmark metrics

To date, there are very few studies that have quantified the regional or national energy used in the production of wine. However, a number of studies do exist from which a comparison for the English benchmark metrics can be compared (table 2.2). The New Zealand wine industry has embraced sustainable winemaking, with individual wineries such as the Mission winery using less than 0.2 kWh per litre of wine production. The Mission Winery is the lowest wine industry energy user in New Zealand. The average New Zealand energy benchmark was calculated at 0.47 kWh/litre (Van der Zijpp 2008), whilst a Canadian study gave a range from 0.21 to 1.9 kWh/litre

(Anon 2006) and the Australian energy benchmark ranged from 0.75 to 2.0 kWh/litre (Anon 2010a). A study of the South Australian wine industry presented an average of 2.14 kWh/litre (Anon 2010a). In Western Australia the Ferngrove winery used 0.25 kWh/litre of wine. The energy use per winery floor area in an Italian study of an Umbrian winery (Cotana and Cavalaglio 2008) was 122 kWh/m^2 which was significantly less than the 190.7 kWh/m^2 recorded in a Californian winery (Smyth 2010).

Nova Scotia's wine industry is a small yet growing wine industry. At the very northern climatic limits of wine production, the industry profile has many parallels with the English wine industry. In 2006, 130 hectares of grape vines in 30 wineries produced nearly 700,000 litres of 'Nova Scotia wine', primarily sparkling and white still wines from hybrid varietals. In a study investigating the life cycle environmental impacts of wine production and consumption in Nova Scotia (Point 2008), a value of 0.52 kWh/bottle (0.38 kWh/bottle from electricity and 0.02 litre/bottle of heating oil) was determined for the industry as a whole, equating to nearly 0.7 kWh/litre.

In summation, comparing the average English benchmark metrics with that measured/calculated in other winemaking regions of the world, English wine with an average production benchmark of 0.557 kWh/litre or 34.92 kWh/m^2 is significantly more energy sustainable than many of the wine regions that currently have data available. However, a number of wineries globally have demonstrated that much lower values can be attained and thus there is still a substantial reduction in energy usage potentially available within the English winemaking industry. As the cost of energy increases, public perceptions about energy use evolve and as the English wine industry expands, it is increasingly important, from economic, environmental and social perspectives, that good energy management and use is widely adopted by producers.

2.6 Good Energy Practise

The wide variation in the size of wineries and production operations create a wide range of technologies, production plant configurations, end-use energy requirements and operating practices. As a result, many different ways to improve energy efficiency and to identify improvement opportunities are possible. This section identifies a number of key areas where significant energy savings can be made in English winemaking. Figure 2.22 presents the distribution of energy expended in production processes for all the English wineries investigated and provides a clear indication of where the most savings can be made. The following lists in order the areas that should demand the highest priority.

- Thermal conditioning: 44%
- Lighting: 22%
- Bottling: 13%
- Sterilisation and cleaning: 8%
- Winery moving machinery: 7%
- Miscellaneous: 3%
- Juice/wine pumping, filtration and mixing: 2%
- Grape processing: 1%

This said however, it is important to appreciate that any winery is a dynamic environment and therefore one area cannot be considered in isolation. Similarly, the ultimate savings achievable in any given area are not proportional to each other. Understanding the energy supply and energy loads within a winery and how they interact with each other is fundamental to reducing total energy consumption. Performance knowledge of individual processes and components is a very important aspect of this evaluation process but should be viewed within the bigger context. For example focusing on improving refrigeration plant operation for cooling needs may overlook the broader implications relating to how and where cooling is used in the winery. Adopting a 'winery system' approach provides the most effective way to achieve large gains in performance and optimise production systems. Likewise, any effective energy improvement project should take into account the important production related parameters listed below; an energy efficient winery is useless if the impact is detrimental to the product quality.

- Winemaking methods and practices
- Winemaking process conditions (temperatures, flow rates, cooling loads)
- Operating practices and winemaking process control (variable or exact)
- Production management practices
- Plant control routines and management
- Maintenance and facilities management practices

Of course, each winery should be evaluated on its own terms and any approach must have access to information. Good monitoring, record keeping, observation and communication are integral to the process. Only when all the variable are considered as part of the bigger picture is it possible to a produce a quality product, whilst still meeting the energy demand in the most effective and efficient manner.

2.6.1 Winery thermal conditioning

The term 'thermal conditioning' is a broad cover all term and is used to describe a wide variety of energy end-uses within the English winery. It is by far the largest energy segment used in the industry, representing 44% of all the energy expended in production and includes all space and process heating, cooling and ventilation requirements, low temperature hot water (LTHW) and chilled water production and covers the energy used by refrigeration plant, air handling units (AHUs), terminal units, fans and associated pumps and control devices. This is equivalent to almost 0.25 kWh/litre of wine produced.

Before considering improvements in the thermal performance of processes and equipment used in the winery, it is important to first consider the condition of the winery building environment. This can be broadly categorised under fabric insulation and continuity and airtightness.

Fabric Insulation and Continuity
The thermal performance of a building element (within a particular construction) is described by its U value (W/m^2K). This is a measure of the heat transmission through the element per degree of temperature difference between the internal and external environments. Thermal bridging typically occurs at the junctions between plane building elements, e.g. at wall/roof and wall/floor junctions, and around openings, e.g. at window jambs, where the continuity of the insulation is interrupted. Thermal bridging increases the heat loss and also the risk of condensation due to the lower localised internal surface temperatures.

Airtightness
The airtightness of a building, or its air permeability, is expressed in terms of air leakage in cubic metres per hour per square metre of the building envelope area when the building is subjected to a differential pressure of 50 Pascals ($m^3/(h.m^2)$@50Pa). Air leakage is defined as the flow of air through gaps and cracks in the building fabric. Uncontrolled air leakage increases the amount of heat loss as warm air (or opposite in cooling applications) is displaced through the envelope by colder air from outside. Air leakage of warm damp air through the building structure can also lead to condensation within the fabric (interstitial condensation), which reduces insulation performance and causes fabric deterioration.

Many of the winery buildings surveyed during the current study were refurbished or adapted existing buildings (primarily farm buildings). Most of the older buildings had a poor thermal envelope, characterised by minimal structural insulation and leaky construction. However, in many of these adapted buildings, there was no internal thermal conditioning and therefore minimal directly attributed energy loss. There was, however, an indirect impact on the wine stored in tanks and bottles. Any increase/decrease in the internal ambient temperature would have resulted in temperature variation of the wine which would have required increased heating/cooling where used. Conversely, during fermentation, the leaky structures would have negated the need for mechanical CO2 removal. Many of the newer or purpose made buildings had better thermal envelopes, often designed and constructed to the relevant building regulations and one new state-of-the-art winery actually exceeded the current building regulations.

Utilising existing buildings for winemaking makes many of the 'big impact' simple design solutions for energy efficiency, such as good site selection or optimised building shape and form, impossible to implement. Generally, imposing a high-performance building envelope on an existing building is also difficult, but not impossible. There are a number of retro-fit examples were good use of insulation and air control have been applied in existing winemaking facilities.

Following a simple walk-through visual observation of the winery structure, highlighting common issues such as fabric deterioration, broken window panes, missing insulation, poorly sealed doors/windows etc., a thermographic analysis could be conducted using an IR camera to visualise areas where the building insulation has degraded or is not present. Figure 2.30 depicts the thermal image taken of a winery in North Carolina.

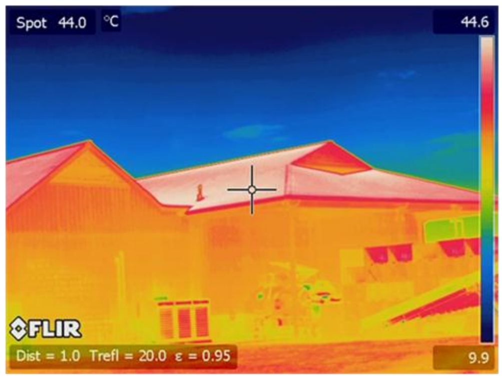


Figure 2.30: Thermal imaging of an existing winery

In most cases, it is easy to apply sufficient levels of additional insulation to improve the structural element's collective heat transfer coefficient (U value) by a significant amount. Figure 2.31 shows additional insulation fixed onto inner surface of a barrel store roof in a Californian winery. In addition to improving the thermal performance of a winery's structural element, adding insulation will also improve the element's integrity and reduce unwanted air infiltration.

Figure 2.31: Good use of structural retro-fit insulation in a barrel room store

Unwanted external heat gains are not a significant all year round problem for most English wineries, but from time to time, extremes in summer-time day temperatures, coupled with direct/indirect solar gain, can lead to overheating in the internal winery environment. In many areas, these isolated extremes can be tolerated, but not in the winery bottle stores. Utilising the building's thermal mass is one way of alleviating the internal/external air temperature variations. In some of the wineries visited a highly insulated enclosure (figure 2.32) within the winery was created to provide a buffer from external temperature fluctuations. An interesting use of deciduous trees to reduce winery overheating was exhibited by one English producer; during full leaf, the trees provided shade (figure 2.33) but during the winter when the leaves had fallen off, the sun was able to shine through, providing some additional daylighting. Only one winery, however, had a dedicated underground cellar (figure 2.34), providing significant thermal isolation from the outside.

Figure 2.32: Example of an aboveground cellar with significant insulation

Figure 2.33: Solar shading using deciduous trees to reduce overheating in winery

Figure 2.34: Temperature control using an underground cellar

Infiltration losses can account for approximately 21% of refrigeration energy during fermentation and cold stabilization in a typical Californian winery. It is unlikely that this would be anywhere near as high in a English winery, but unwanted air movement resulting from poor airtightness is still something that has an implication on energy used and therefore must be reduced. The airtightness of a winery can be improved though the proper management of building openings. Simple actions such as fitting seals and draft excluders or replacing ill-fitting doors and windows will have immediate effect. In some occasions, however, openings such as production space doors will need to be open for prolonged periods. In these situations, rapid roll doors or flexible strip curtains (figure 2.35) can be used to minimise air infiltration whilst permitting vehicular movement in and out of the building.

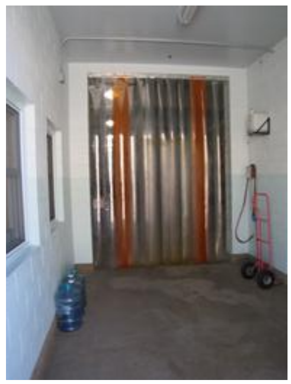


Figure 2.35: Use of strip curtains to reduce unwanted air movement through an open door

The vast majority of the English wineries surveyed had no internal thermal conditioning (63.5%). A few had partial thermal conditioning (26.5%) in bottle storage areas and specialist vinification spaces. Only one of the surveyed wineries had a fully conditioned internal production space, utilising dedicated HVAC (heating ventilation and air conditioning) plant and distribution.

Where some form of thermal conditioning is present, a number of measures can be introduced to reduce energy usage of HVAC plant and systems:

- Reducing the heating/cooling load or the duty of the system can yield significant savings. For example, installing low-e windows or internal and/or external window shades, using energy-efficient lighting (with minimal heat output) and turning off unnecessary equipment can reduce internal heat gains thereby reducing the cooling load. Likewise, window coating or blinds can be used to minimize heat loss. Control (reduce) the amount of tempered air delivered to a conditioned space relevant to the controlled variable, e.g. heating/cooling load, delivery temperature, ventilation requirements and/or air circulation or air changes. Ensure that ducted distribution systems are sealed to minimize unwanted air leakage and insulated to remove unnecessary heat gains/losses. If the winery has a controlled internal environment, conditioned via a dedicated HVAC installation, setting internal space temperatures, where applicable, to lower values during the winter or slightly higher during the summer during non-production times can reduce heating or cooling loads.

- Utilise available environmental conditions/resources such as night-time air cooling. Supplying air directly from outside during the night brings in air at lower temperatures which can reduce energy expended on mechanical cooling. Night-time cooling can be improved by using thermal mass within the winery enclosure. This measure is generally applicable to storage areas such as aging or bottle/barrel storage. Thermal de-stratification can be used to equalise air temperature distribution within a storage space via economic directional ceiling fans, thereby preventing hot air rising to the ceiling or cold air sinking to the floor, leading to poor thermal conditioning or false room temperature measurement.
- Improve the efficiency of system components. Select units with a high Energy Efficiency Ratio (EER) or more appropriately, high European Seasonal Energy Efficiency Ratio (ESEER). Use fan/pump and associated motors that are more efficiently sized. Implement a regular maintenance plan to ensure equipment is operating to its stated performance. Devise an appropriate schedule to check, calibrate, inspect, clean, repair and replace when necessary. Predictive maintenance through system condition monitoring can indicate significant changes in system performance, directing specific maintenance actions to offset reduced system performance and ultimately, system failure.
- Improve the control and functional co-ordination of systems and components. Instigating simple measures that ensure that HVAC equipment is off when not needed or turned off earlier to remove overrun can yield savings. Introducing zone control, night-setback control or adjusting thermostat settings for seasonal changes can also be beneficial. Ensure that outdoor air dampers are closed or backdraft dampers are in place and operable as that can control unwanted air infiltration. If fans are used to remove unwanted CO2 in the fermentation area, rather than opt for manual on/off control, consider using demand control ventilation based on the indoor air quality (e.g. CO2 sensing).

Recent research has indicated that fabric forced-air ducts distribute air 24.5% more efficiently than conventional sheet-metal ducts. By diffusing the conditioned air more widely in a shorter time there is a resultant reduction in the HVAC load. Figure 2.36 details a fabric forced-air ducted AC installation in an English winery bottle store.

Figure 2.36: A fabric forced-air ducted AC installation

Evaporative coolers (commonly referred to as swamp coolers in many parts) can be used (under certain conditions) to replace the cooling activities of tradition AC refrigeration. In many cases swamp coolers can use up to 75% less electricity than traditional AC. Figure 2.37 details a ducted evaporative (swamp) cooler installed in an English winery.

Figure 2.37: A ducted evaporative (swamp) cooler

In a number of wineries, localised electric (resistance) heaters were used to provide space heating (figure 2.38). The systems, whilst inexpensive to install, can be quite high in energy use. The heating element inside each electric heater is an electrical resistor and works on the principle of Joule heating. Whilst most electric resistance heaters at the 'point of use' convert nearly 100% of the energy in the electricity to heat, as most electricity is produced from fossil fuel generation, the 'point of production' efficiency may be less than 30%. Considering the use of alternative heating modes or heat pump technology can lead to significant savings. In high-bay spaces, it is better to replace convective 'blown air' heaters with radiant tube or plaque heaters. Heat pumps whilst using electricity can deliver two or three units of heating energy for every one unit of electricity purchased due to their ability to thermally transform low grade energy into a higher grade form.

Figure 2.38: Electric forced air, resistance heater

Winery Refrigeration

Refrigeration and related cooling plant and equipment are the single largest users of energy in most wineries worldwide. This study indicates that a significant proportion of English wineries employed some form of mechanical refrigeration equipment for either production chilling needs or space AC requirements. All of the mechanical refrigeration systems listed in the survey used vapour compression refrigeration. The vapour compression cycle uses a circulating liquid refrigerant as the heat transfer medium which absorbs and removes heat from the space/fluid to be cooled and subsequently rejects that heat to another space/fluid. Figure 2.39 schematically illustrates the components and operation of the vapour compression cycle.

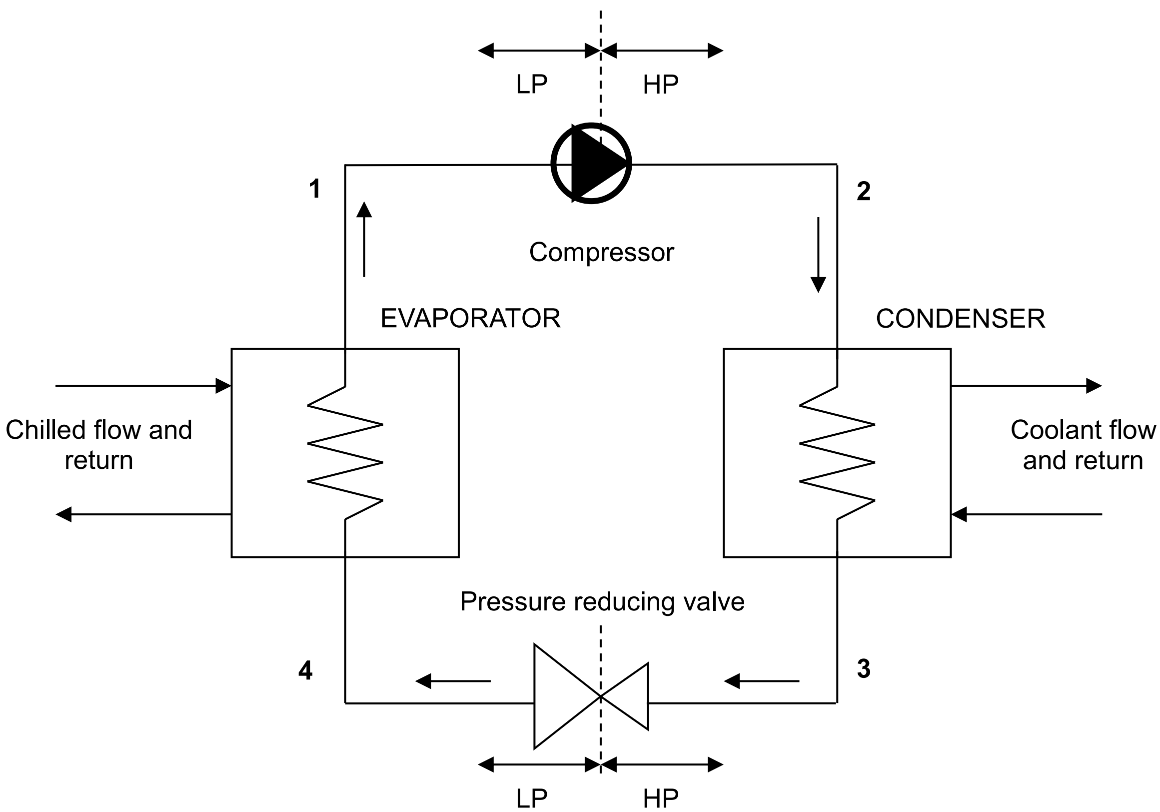


Figure 2.39: Schematic diagram of the vapour compression components and operation

- From 1 to 2: The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in the temperature, because a proportion of the energy put into the compression process is transferred to the refrigerant.
- From 2 to 3: The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process de-superheats the gas before it is then turned back into liquid. The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipework and liquid receiver, so that the refrigerant liquid is sub-cooled as it enters the expansion device.
- From 3 to 4: The high pressure sub-cooled liquid passes through the expansion device, which reduces its pressure and controls the flow into the evaporator.
- From 4 to 1: Low pressure liquid refrigerant in the evaporator absorbs heat from its

surroundings. During this process it changes its state from a liquid to a gas, and at the evaporator exit it is slightly superheated.

Depending upon the form of mechanical cooling needed the refrigeration equipment used in English wineries can be simply categorised as being for either 'spilt' cassette AC units used for simple space AC requirements (figure 2.40), or packaged chiller units used for production cooling applications. All of the packaged chiller units observed in English wineries utilised air cooled packaged chillers (figure 2.41). Water cooled 'evapourative chiller units are more common in other wine producing regions.

Figure 2.40: External spilt condenser/fan unit for AC

Figure 2.41: External packaged chiller unit (vertical air discharge) for process cooling

The physical location of the chiller unit can have a dramatic impact upon system performance. In many instances, the winery chiller(s) is located in a position that is remote from public view. Chillers should be located as near as possible to the cooling load, to reduce transmission losses.
Direct sunlight should be avoided, as solar gain on the condensing coil can severely reduce the system's operating efficiency. A shaded location on the north or east side of a building is good, perhaps covered by an open awning. It is important that the canopies or roofs of open-sided shelters do not restrict the air flow on chillers with vertical air discharge. If the chiller has a horizontal discharge, the discharge should not face into the prevailing wind or physical

obstruction. Similarly, the air inlet should be located at least 1 metre from walls and other obstructions. Building elements or other equipment can also impact the chiller by creating downdrafts and eddy currents that may also restrict air flow. Chillers located indoors should pay particular attention to potential restrictions and chillers designed for indoor applications should not be used outdoors (figure 2.42). Of particular interest is the use of portable packaged chiller units (figure 2.43). In a number of wineries, the heat from the condenser during cooling operation was exhausted directly into tank area, leading to a heat gain in the general area which had a knock on effect in the form of heat gain in the wine in the tank, leading to a greater refrigeration load. Where possible excess heat should be directed away from the cooling load.

Figure 2.42: Fixed packaged chiller unit located indoors

Figure 2.43: Portable packaged chiller unit

In nearly all large winery refrigeration systems, the chilling plant consists of two loops; the refrigerant loop (as detailed previously) and a second closed coolant (typically glycol) loop providing cooling to the winery processes. Nearly 26% of the wineries surveyed had a fixed glycol refrigeration installation (3 wineries had an in-line heating installation) and a further 16% utilised a fixed glycol refrigeration installation augmented with a portable glycol chiller/heater with integral tube-in-tube heat exchanger. Glygol loops provided cooling (and heating in some instances (figure 2.44) to distributed fan coil units (figure 2.45) for space conditioning and/or integral tank heat exchangers for juice/wine cooling processes (figure 2.46).

Figure 2.44: In line glycol heating (seldom used in many English wineries)

Figure 2.45: Fan coil unit

Figure 2.46: Fixed glycol cooling connection to tank heat exchanger

In many instances in English wineries, where possible, the use of mechanical cooling was avoided altogether. Almost 37% of the wineries surveyed reported no form of refrigeration used to control space or wine temperatures. However, a number of wineries utilised alternative cooling methodologies. About 10.5% of the wineries surveyed used a form of evaporative cooling to reduce unwanted heat gain and another 10.5% use mains water cooling via an integral heat exchanger to control tank temperatures. In evaporative tank cooling a capillary material such as hessian cloth was draped over the tank and a small amount of water applied to the material. As the water evaporates into the surrounding air, the phase change activity extracts heat from the tank underneath, thereby providing a limited level of uncontrolled cooling. Mains water cooling was achieved by providing a trickle flow of water (at ground supply temperatures) through an integrated tank heat exchanger. Figure 2.47 depicts two forms of water cooled tank; lid mounted heat exchanger (left) and tank mounted heat exchanger (right). Whilst water waste may be an issue, flow rates are usually so low that their overall impact on water usage is negligible.

Figure 2.47: Water cooled tanks; lid mounted heat exchanger (left) and tank mounted heat exchanger (right)

One English winery is considering underfloor cooling, using mains water flowing through pipes embedded in the concrete floor of the bottle storage room as a viable option to offset electrical cooling loads.

Load management and duration can also be considered where it can reduce refrigeration loading in areas where localised ambient temperatures are excessive. This is seldom the case in the UK, but high temperatures are sometimes possible. In these cases, if possible, consider flexibility with regard to receiving grapes during harvest time, for example picking grapes during the night or early in the morning. Consider reducing magnitude and duration of cooling loads. For example, 10,000 litres of juice to be cooled in 6 hours by 10°C will require a cooling input of 69,033kJ/hr or 19.2kW or 5.75RT (refrigeration tonne). However, if the duration is changed to 12 hours then the cooling will be will be 34,516kJ/hr or 9.6kW or 2.88RT (note: 1 kW = 3.6 MJ/hr = 0.3RT). This will have a significant impact of the size and loading of the refrigeration plant although additional heat gains will have to be considered.

Where possible, optimize fermenter volumes to ensure maximum tank heat exchanger performance, identify opportunities for wine to wine heat exchange (heat exchange chilled wine leaving cold stabilisation with warm wine entering cold stabilisation) and ensure effective tank mixing (particularly important for temperature sensing instrumentation).

To insulate or not to insulate is a big issue in the operation of winery tanks. None of the wineries involved in the current study utilised permanently insulated tanks. There are 3 primary types of tank insulation commonly used in winery applications; Spray-on for large applications, foil over bubble wrap, and a rigid foam with an outer shell. Approximate energy savings generally vary from 20 to 35%, depending on the type of insulation system. Un-insulated tanks should not be located outdoors whenever possible, and in enclosed (unconditioned) spaces, insulation should always be considered. If the tank space is cooled to a lower ambient temperature, heat gain to the tanks is minimal, allowing the aesthetic benefits of the tanks to be in full view for any visitors, although higher overall building energy loads will result.

Figure 2.48: Cold stabilisation with external frozen condensation on exposed heat exchanger surfaces

In many winemaking processes, such as cold stabilisation, the wine is chilled down to about -4ºC to 0ºC over several days. In a study by Dugger (2008), the merits of insulation for tanks during cold stabilisation are presented. In the study, two white wines were traditionally glycol cooled in a tank with and without insulation and the energy intensities compared. The un-insulated tank required 0.317 kWh per litre whilst the insulated tank required only 0.006 kWh per litre. In many English wineries significant savings could be made by even using a layer of simple plastic bubble wrap insulation during tank cooling periods. Additionally, moisture in the air surrounding the tanks results in surface condensation on the tanks and due to the very low flow glycol temperatures, ice forms (figure 2.48). This change of state absorbs significant energy, changes the heat transfer characteristics, leading to an increase in the refrigeration load. Karousou et al's (2007) study calculated that 0.029 kWh of cooling is necessary per litre of red and white wine for cold tartaric stabilisation using glycol cooling at -10°C. Another method to remove excess bitartrate acid that has been investigated is electro-dialysis. Electro-dialysis is a membrane process driven by an electric current, moving the tartrate ions from the wine through a membrane to an aqueous solution. Electrodialysis uses only about 12% of the energy used in cold stabilization, because no freezing and reheating is required.

From the current study, refrigeration for process cooling accounts for much of the electricity used in winemaking and is therefore a necessary component of the modern English winery. Where refrigeration has been fully employed in an English winery, electrical energy usage is only slightly lower than that experienced in other winemaking regions. In a study of a Western Australian winery (Anon 2010a), the electrical refrigeration load was calculated to be 0.35 kWh per litre of wine produced and in a similar study of a Californian winery (Smyth 2010), the equivalent value was 0.32 kWh/litre.

The applicability of refrigeration plant and equipment energy efficiency measures (following all measures to avoid or reduce mechanical cooling loads) greatly depend on the refrigeration system size. Small to medium sized winery refrigeration chiller units should be sized for the harvest period, which lasts 4 to 8 weeks of the year. It is accepted that they may significantly oversized for the balance of the year and therefore systems must be selected that demonstrate efficient operation at reduced capacity. Larger wineries have more scope and can consider 'sorption' refrigeration as a viable alternative. In general refrigeration equipment efficiency improvements should consider:

- Monitoring system performance can be very beneficial in quantifying the opportunity to address poor part-load efficiency whilst also indicating plant deterioration. Included in this are the refrigerant charge (low refrigerant charge affects many small direct expansion (DX) systems and can increase the refrigeration load by 10%), suction line filters (debris will cause increased pressure drops) and contaminants in the refrigerant (a 2% improvement can be realised through removal of unwanted oil or water)
- Compressors
    - Savings can be made through good sequencing and control of compressors by optimising enhanced strategies and set points, such as optimizing compressor operation to reduce part-load inefficiency. Base loading with screw compressors and trimming with reciprocating compressors is a standard configuration.
    - Consider heat recovery from the compressor oil.
    - Using Floating Head Pressure (FHP) can represent a significant opportunity for reducing the energy consumption of refrigeration compressors (particularly smaller systems) and requires additional fan power to reduce compressor power.
    - Variable Speed Drives (VSDs) on screw compressor motors used below a part-load ratio of 95% deliver equal capacity with lower electrical power requirements than a fixed speed compressor. At a part-load ratio of 27%, the VSD operation requires 40% less electrical power than the fixed speed case whilst providing the same refrigeration capacity.
- Condensers
    - Variable Speed Drives (VSDs) on condenser fans offer savings in much the same way as indicated above from compressor operation. Selecting an appropriate condenser fan capacity modulation can result in significant energy efficiency. Note: it is important to evaluate the extent that the condensing (or head) pressure can be floated.
    - Consider heat recovery from the condenser. Any heat recovered will be at a low temperature and probably only useful in a pre-heating role.
- Evaporators
    - Automatic purgers installed on evaporative condensers remove air and other non-condensable elements thereby improving the performance of the refrigerant.
    - Variable Speed Drives (VSDs) on evaporator fans offer savings in much the same way as indicated above from compressor operation.

Where possible, old refrigeration plant (figure 2.49) should be replaced by modern, more efficient equipment. In addition, equipment should be regularly maintained and components such as the insulation on refrigeration pipework and/or chilled water/glycol pipework such be the highest quality. Figure 2.50 depicts two examples of poorly insulated refrigeration pipework. On the left, insulation is missing from significant runs and fittings of glycol pipework, and the existing insulation is of a poor quality. The image on the right shows the effect of missing insulation from pipework from the evaporator in old refrigeration plant. A layer of ice formed through ambient moisture condensation on the exposed pipework increases heat gain and therefore plant inefficiency. Note that good quality insulation (EPDM closed cell) is used on other pipework.

Figure 2.49: Old, inefficient refrigeration plant

Figure 2.50: Missing or poor insulation on refrigeration pipework

The application of PCM ‘coolth’ through ice storage technology is an interesting alternative option currently being explored in reducing refrigeration loads (figure 2.51). A primary reason for using ‘coolth’ storage is to reduce on-peak electric demand by moving to off-peak periods of operation or operating over a 24 hour period. By designing the system around a 24 hour chiller operation, the size of the chillers and associated plant required is significantly reduced when compared to conventional chillers and plant sized for an instantaneous peak load. A typical ice storage system comprises chilling plant that is based on 50% of the peak cooling load with the balance ice storage. By operating around the clock, the chiller efficiency is improved as it is designed to operate near to it's full capacity, reducing part-load losses.

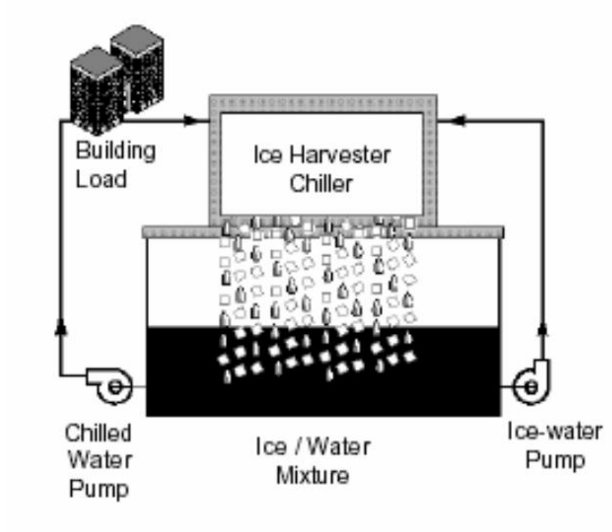


Figure 2.51: PCM 'coolth' storage system

2.6.2 Winery Lighting

Lighting in the English winery accounts for on average 22% of the energy expended in producing wine, equivalent to 0.12 kWh/litre wine produced. Lighting is used to create a level of illumance throughout the winery spaces suitable for the ambient and/or specific conditions necessary. For example, background ambient illumance of 50 to 100 lux may be used in general open production or storage areas, whilst higher levels of 300 to 500 lux may be necessary in the laboratory areas or locations with intensive activities. In some areas it may be possible to consider localised lighting opposed to general lighting which can reduce excessive lighting loads.

A wide range of lighting systems (lamps and luminaires) are available and are used by many of the English wineries surveyed. Figure 2.52 illustrates the range of lamps typically available. In many of the wineries visited fluorescent fittings were used extensively, from production areas to stores. This was in part due to the adaptation of existing buildings into winery spaces and the existing lighting installation maintained. Metal halide and mercury vapour lamps were used by a few wineries in the main production and storage areas and some wineries had high-pressure sodium fittings used in high bay applications. Metal halide lamps dominated external and security applications. Fluorescent, compact fluorescent (CFL) and incandescent lamps were typically found in retail and administrative areas. Tungsten halogen lamps were used in significant numbers as spotlights in the majority of retail/wine tasting areas. LEDs were used by several wineries, but as of yet, seemed to be used in small token applications, normally replacing spotlight fittings. Some emergency lighting used LED fittings but most used T-5 fittings.

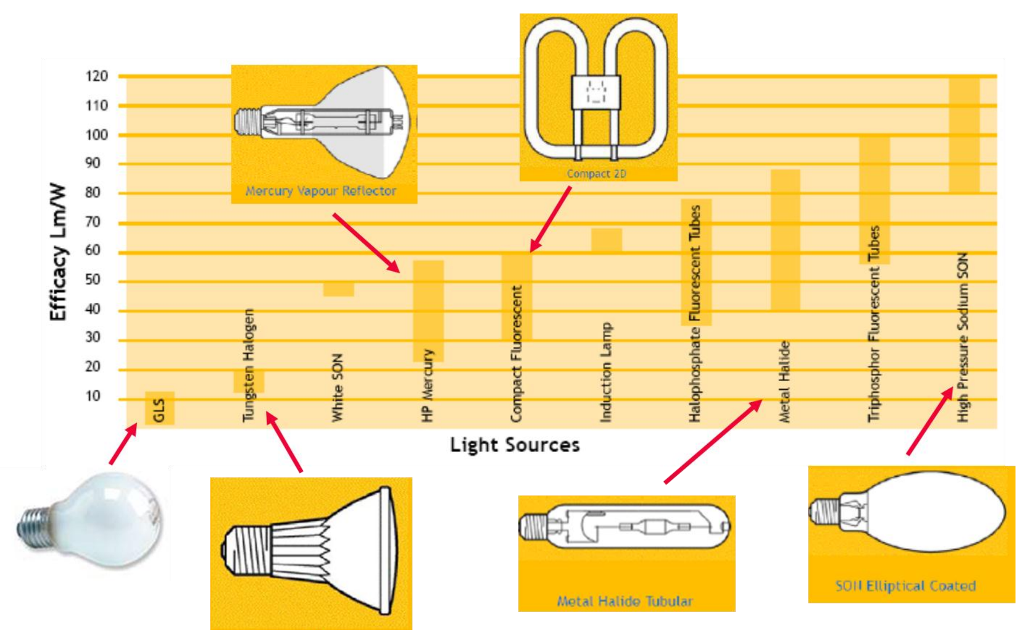


Figure 2.52: A range of the various lamp types available

Replace incandescent lights with fluorescent lights, CFLs or LEDs
The fluorescent lamp has a lifespan roughly ten times longer than an incandescent light and is three times more effective in lighting provided. LEDs are significantly better. Typical energy savings are can be up to 75% per lamp.

Replace magnetic ballasts with high frequency electronic ballasts.
A ballast is used to regulate the starting current for a lighting fixture and maintain a steady output of light. Electronic ballasts (figure 2.53) save up to 30% power over their magnetic counterparts, providing silent dimming capabilities, longer lifespan, quicker start-up and lower heat output. Ensure the correct light and ballast combination.

Figure 2.53: High frequency electronic ballast for T-8 fluorescent lamps

Replace T-12 tubes with T-8 tubes or T-5 tubes.
The T-(number) coding for fluorescent lamps quite simply refers to the tube diameter in 1/8-inch increments (e.g. T-12 means 12/8 inch and T-5 means 5/8 inch or). T-12 lamps have a high light output, but compared to T-8 and T-5 lamps, have a high energy consumption and suffer from a low efficacy, poor lamp life, significant lumen output deterioration with a poor colour rendering index. Typical energy savings from the replacement of a T-12 by a T-8 are around 30% and slightly better for T-5. T-5 lamps have a slightly better output performance at higher temperatures (figure 2.54). There are other benefits such as longer life-span. In figure 2.55, the T-8 fluorescent lamp fittings were replacement fittings for existing T-12 lamps in an English wine bottling area. The T-5 fluorescent lamp fittings were installed in new English winery.

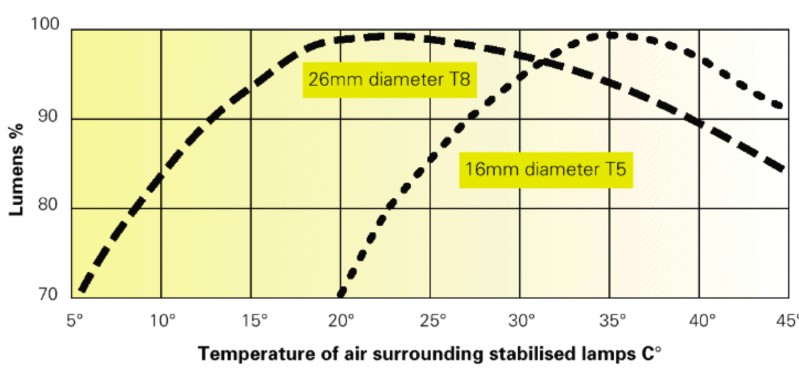


Figure 2.54: T-8 versus T-5 lamps in different ambient temperatures

Figure 2.55: T-8 (left) and T-5 (right) fluorescent lamp fittings in English wineries

Replace standard metal halide HID and consider voltage reduction

High Intensity Discharge (HID) lights are typically used in large production areas and external areas (figure 2.56). Traditional HID lighting can be replaced with high-intensity fluorescent lighting in general production areas leading to significant savings, around specific investments are estimated at £0.14/kWh-saved. If replacement is difficult, reducing the system voltage may be considered. Units mounted in the distribution board regulate the flow of electricity to fixtures, thereby reducing voltage and saving energy, without impacting the perceptible light. Voltage controllers work with high intensity discharge (HID) and fluorescent lighting systems. Typical payback for lights that are used 24 hours per day can be as low as one year.

Figure 2.56: External security fitting with a metal halide lamp (left) and high bay metal halide HID fitting used in a production area (right)

Consider High Pressure Sodium Lights

Where colour rendering is not critical, high pressure sodium lamps offer energy savings of 50 to 60% compared to some other lamps. High pressure sodium lamps also produce less heat, reducing cooling loads. In a few wineries high pressure sodium fittings were used in external work areas (figure 2.57) and in one winery were used in the tank area (figure 2.58).

Figure 2.57: External high pressure sodium fittings

Figure 2.58: High pressure sodium fittings used in a general tank area

Light Emitting Diodes (LEDs)

LED lighting has many advantages over many lighting options, including significant energy savings, suitability for retro-fit installation and commercial applications, long life and reduced heat output. However these advantages must be considered in context with their disadvantages:

- LEDs are currently more expensive, price per lumen, on an initial capital cost basis, than most conventional lighting technologies.
- Due to their ambient temperature dependence, adequate heat-sinking is required to maintain long life.
- Voltage sensitivity, LEDs must be supplied with the voltage above the threshold and a current below the rating.
- Light quality and colour rendering can be perceived to be different
- LEDs are difficult to use in applications requiring a spherical light field

This said, the evolution of LED technology is dramatic and many new LED luminaires are becoming available that can overcome some of their previous disadvantages. Figure 2.59 depicts some of the common types and application.

Figure 2.59: LED spotlight fitting (left), retro-fit luminaire strip LED (centre) and LED external fitting (right)

Luminaire design

It is important to consider good luminaire design and ensuring a good Light Output Ratio (LOR) is vital. The light output from louvered diffuser luminaires of the same type/category can vary from between 37% and 76%. When replacing fluorescent tubes, fit effective reflectors. Often the louver side 'Cheek' reflectors are not to the height above the fluorescent tube to provide the maximum light output. To improve this inferior design it is possible to either fit a T5 adaptor with a reflector or a T8 reflector to the existing T8 fluorescent tube to maximise the LOR.

Maintenance

Ensuring that lighting fixtures are cleaned regularly can improve their light output, resulting in greater energy efficiency. Figure 2.60 indicates the fall in performance over time with and without regular cleaning. This also applies equally to daylighting components such as windows, skylights, etc.

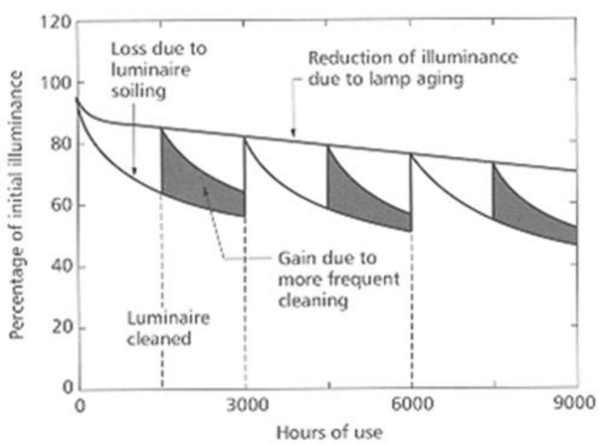


Figure 2.60: Luminaire cleaning (CIBSE, 2004)

Lighting controls

Immediate savings can be made by switching off lights when the space is not occupied. If possible and wiring permits, fit more switches per bank of lights. More switching control will allow lighting to be operated where and when it is needed in larger spaces. Good application of lighting controls (timers, photocells and occupancy sensors) can automatically switch off lights during periods when the space becomes unoccupied. Occupancy sensors, for example, can save up to 20% on the energy used for lighting. Daylighting, when used with photocell sensors and lighting controls can have a significant impact of lighting energy use when appropriate to do so.

Non-powered lighting

There are some applications where powered lighting can be removed. On example is exit signage. Tritium exit signs are self-luminous and do not need any power supply. The lifetime of these signs can be up to 10 years although they are quite expensive.

Daylighting

Efficient use of natural light, where appropriate, will minimize the need for artificial light in various areas within the modern winery. Of course, not all parts of the winery may be suitable for daylighting, such as the bottling facility, laboratory, tasting room and warehouses, but it is appropriate for many areas that are used in daytime hours by people. The associated savings will vary widely depending the facility and buildings, it some spaces increasing levels of daylight within rooms can reduce electrical lighting loads by up to 70%.

Various daylighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building. Daylighting technologies include properly placed and shaded windows (figure 2.61), atria, angular or traditional (flat) rooflights, clerestories, light shelves and light ducts. Clerestories, light shelves and light ducts (figure 2.62) utilize angles of the sun and redirect light with walls or reflectors.

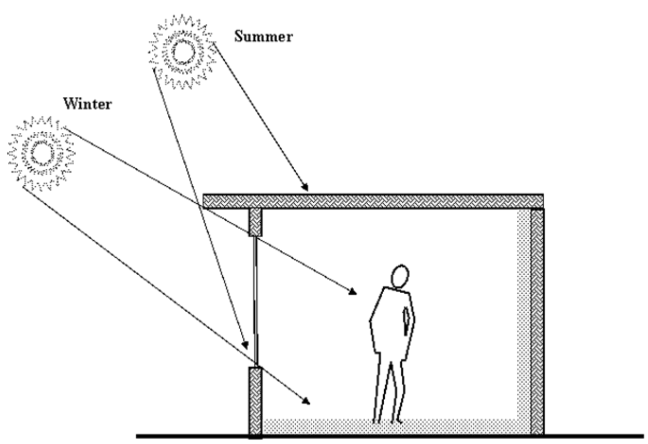


Figure 2.61: Seasonal daylighting

Unlike conventional skylights, an efficient daylighting system may provide evenly dispersed diffuse light without creating heat gains. The reduced heat gains will reduce the need for cooling compared to skylights.

Figure 2.62: External and internal images of the daylighting system in the Pinot Noir facility in a Californian winery

2.6.3 Winery Bottling

Bottling activities in the English winery accounts for 13% of the energy expended in producing wine, equivalent to over 0.07 kWh/litre wine produced. The actual processes and equipment used varies significantly, but includes wine filling, crown capping and disgorging, corking, wiring, foiling and labelling and packaging. The survey identified that 31.5% of the wineries operate a fully automated, mechanical bottling line whilst a further 16% had a partially automated, mechanical bottling line (that is some manual intervention was necessary. Almost 31.5% had a manual bottling line with some important automated, mechanical intervention. Interestingly, 21% of the surveyed wineries had completely manual bottling processes with no energy using equipment necessary. Nearly all the mechanical equipment surveyed was heavily dependent upon electric motor or pneumatic (compressed air energy) devices.

Motors

Motors are used extensively throughout a winery to operate HVAC equipment and to drive much of the process equipment (figure 2.63). The following section is headed under bottling equipment, but is also very relevant to the other areas of winery activity that use motors. To reduce motor energy use, it is important to catalogue the many motors used in the winery, along with their operating conditions and specifications. Thereafter the needs and actual use can be compared and an evaluation based on energy consumption and relevant motor size carried out. Sizing motors correctly avoids unnecessary energy losses. The following lists some of the areas where savings can be made:

- Using high efficiency motors can reduce energy losses through improved design, better materials, tighter tolerances and improved manufacturing techniques and properly installed they run cooler and therefore have higher service factors, longer bearing and insulation life and less vibration. High efficiency motors tend to be economically viable when replacing an old motor, the argument is less viable when replacing a motor that is still working. A payback period of 3 years is typical.
- Variable Speed Drives (VSDs), as previously discussed, permit better match speed to load requirements for motor operations. The actual savings may be up to 60% depending on the size of the motor system and usage pattern.
- Replacing belt drives with direct couplings may save up to 4%, giving a simple payback period of 0.8 years.
- Proper maintenance will prolong motor life and predict motor failure. Preventive maintenance avoids unexpected downtime of motors and should include voltage imbalance, motor ventilation, alignment, lubrication, and load consideration. Predictive maintenance is based around temperature, vibration and RPM observation. Conducting regular maintenance could save up to 30% of total energy used.

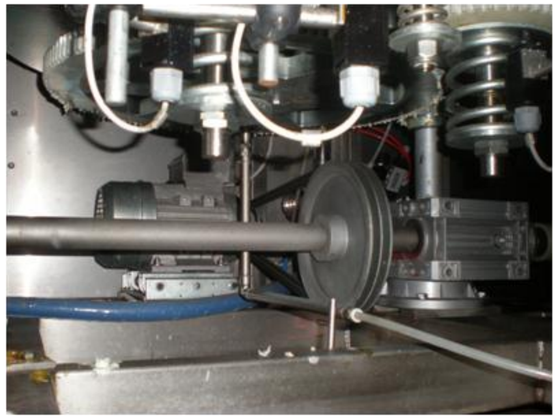


Figure 2.63: Motor, gears and actuating devices beneath bottling line equipment

The implementation of the EU's new eco-design directive 2005/32/EC imposes mandatory minimum efficiencies for a range of low-voltage electric motors. Covering electric motors in the range 0.75 to 375kW, the Directive replaces the voluntary agreement on motor efficiency standards that has existed since 1998. Previously, motors of occasional use could be rated EFF3, regular use at EFF2 and continuous use at EFF1 (the highest efficiency rating). From 2015, the minimum efficiency for motors from 7.5 to 375kW will be IE-3, and from 2017, the obligation of IE-3 will be extended to the motors from 0.75kW to 5.5kW, where IE-3 is highest rated efficiency.

Compressed Air

Compressed air is used mainly in the bottling facility with some used in grape processing activities such as pressing. In this study, bottling activities accounted for 13%, of which a significant proportion was used by compressed air systems. The survey identified that 42% of the wineries had a fixed compressed air installation and a further 21% had a portable compressed air installation (note: one winery hired its compressed air system during harvest and bottling periods). Over a third of the surveyed wineries (37%) had no compressed air requirement.

Figure 2.64: Older air compressor unit located outside in dedicated lean-too shelter (left) and internal packaged air compressor unit, complete with integrated dryer (right)

Compressed air systems have a poor efficiency, typically from start to end-use is around 10%. Due to this inefficiency, compressed air usage should be avoided where possible. If compressed air is necessary, it should be kept to a minimum, constantly monitored and other non-pneumatic alternatives considered. Many opportunities to reduce energy in compressed air systems are available and are not that expensive with very short payback periods. Energy savings of up to 50% are possible, primarily from:

- Reducing compressed air usage where possible can have a significant impact. Turn off unnecessary compressed air lines and remove equipment that is no longer using compressed air. Solenoid valves are a simple installation device that can give good control on which lines are charged or not. Use alternatives to compressed air such as:
  - Air motors should only be used for positive displacement pumps
  - AC cooling of electrical cabinets should avoid compressed air vortex tubes
  - Vacuum pumps should be applied instead of compressed air venturi methods.
  - Cooling, aspirating, agitating, mixing, or package inflating: use blowers instead of compressed air
  - Brushes, blowers or vacuum pump systems should be used for cleaning parts or removing debris
  - Moving parts: blowers, electric actuators or hydraulics should be used instead of compressed air.
  - Blowguns, air lances and agitation: low-pressure air should be used instead of high pressure compressed air.
  - Consider efficient electric motors for tools or actuators.
- Regulate compressed air pressure, duration or volume by pressure regulators on specific production lines or on the supplied equipment.
- Repairing leaks. Air leakage can be a significant source of wasted energy. On average, poorly maintained plant can lose between 20 to 50% of total compressed air produced. Good leakage prevention can reduce wastage to less than 10%. The most common areas for leaks are couplings, hoses, tubes, fittings, pressure regulators, open condensate traps and shut-off valves, pipe joints, unions and thread sealants.
- Reducing the pressure drop across the system can reduce energy consumption. Flow restrictions, such as obstructions or increased friction, require wasteful higher operating pressures.
- Compressors should avoid partial load operation. For example, unloaded rotary screw compressors can consume up to 35% of full-load power while delivering no compressed air. In essence, good control is necessary. Start/stop, load/unload, throttling, multi-step, variable speed and network controls are options for compressor controls.
- Reducing the inlet air temperature reduces energy used by the compressor. In many cases inlet air can be taken directly from outside the building, improving performance. The position of the compressor is therefore very important. Roughly speaking, every 3°C will save 1% compressor energy.
- Variable Speed Drives (VSDs), as previously discussed, permit better match speed to load requirements for motor operations.
- Sizing the pipe diameter correctly (over undersized pipe) can reduce annual energy consumption by 3%. Inadequate pipe sizing causes increased pressure losses and leakage.
- Consider heat recovery for water pre-heating. Up to 90% of the electrical energy used by

a large air compressor is converted into heat. A heat recovery unit could recover up to 50% of this waste heat for space heating or water heating applications in the winery. Figure 2.65 illustrates potential waste heat generation for different compressor usage and size.

- Replacing belt drives with direct couplings (as above) may save up to 4%, giving a simple payback period of 0.8 years.
- Reduce the air compressor discharge pressure. Potential savings and payback periods vary greatly depending upon each specific situation.

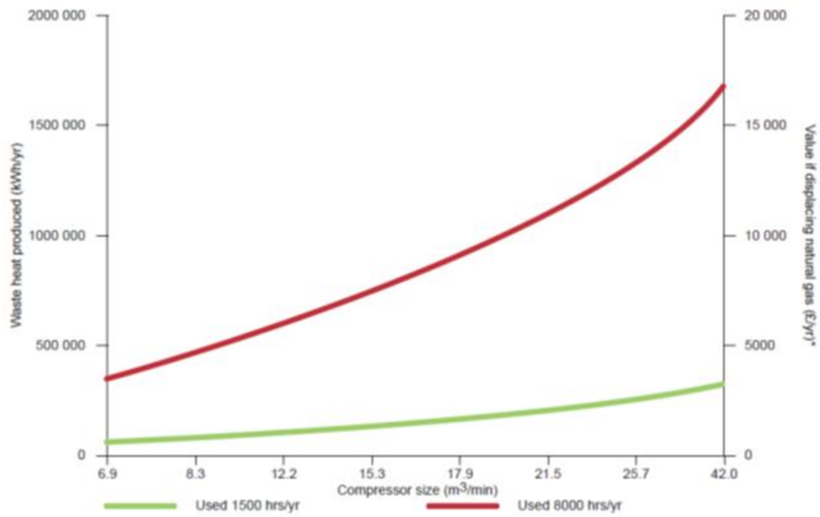


Figure 2.65: Waste heat recovery for different compressor usage and size (Good Practice guide 1998)

- Good monitoring (and associated maintenance) can save a lot of energy in compressed air systems and includes:
    - Installing pressure gauges to monitor pressure drop across across dryers, filters, etc. and installing temperature gauges across the compressor and cooling system to problems. Dew point temperature gauges should also be used to monitor the effectiveness of air dryers
    - Flow meters to measure the quantity of air used and kWh meters and hours run meters to monitor usage.
    - Check air distribution pipework, especially on modified installations to ensure no air is flowing to unused equipment or obsolete parts of the system.
    - Check for flow restrictions of any type in a system.
    - Check for compressed air use outside production hours.
- Maintenance. Poor maintenance can lower the compression efficiency and increase air leakage, leading to increased operating temperatures, poor moisture control and excessive contamination. Good maintenance includes:
    - Use properly sized air regulators.
    - Keep the compressor and intercooling surfaces clean and foul-free and consider adding filters in parallel that decrease air velocity which decrease air pressure

drop.

- Keep motors properly lubricated and cleaned. Poor motor cooling can increase motor temperature and winding resistance, shortening motor life whilst adding to energy consumption. Compressor lubricant should be changed every 2 to 18 months and checked to make sure it is at the proper level.
- Inspect fans and water pumps for peak performance.
- Inspect drain traps periodically to ensure they are not stuck in either the open or closed position and are clean.
- Maintain the coolers on the compressor to ensure that the dryer gets the lowest possible inlet temperature.
- When using compressors with belts check belts for wear and adjust them.
- Replace air lubricant separators according to specifications.
- Check water-cooling systems for water quality (pH and total dissolved solids, flow rate and temperature).

2.6.4 Winery sanitation

Winery sterilisation and cleaning activities on average accounted for 8% of the energy used in the surveyed wineries, equivalent to over 0.04 kWh/litre wine produced. This includes all equipment used in hot water and steam production, associated pumping and power washers. Not all cleaning/sterilising activities require heated water, thereby offsetting a significant amount of energy usage and water waste. Chemical cleaning agents are very common and common in a range of different types for different applications. Ozone, sometimes used for barrel cleaning, can offset around 6 litres of warm water per barrel. Cleaning and sanitation is of the upmost importance for the modern winery and crucial to producing a quality product. From an energy conservation point of view, a clean working environment is good for equipment and can maximise plant efficiency.

Winery sanitation activities can be classified as being either directly related to the production process, bottle or barrel washing, for example, or maintaining a clean working environment such as washing floors. Rosenblum's (2007) study determined that 2.1 litres of hot water was necessary per litre of wine produced for cleaning activities. The vast majority of sanitation processes conducted within the English winery are carried out using hot water or steam. Hot water/steam is produced by some form of combustion process (figure 2.66) or through electrical resistance heating (figure 2.67). A winery will also use a sizable amount of hot water for domestic appliance requirements. All wineries will have sanitary appliances, culinary activities and working laboratory spaces. It is therefore essential that these areas have quality hot water. Like production hot water, this domestic hot water can be heated by a variety of ways.

Figure 2.66: Gas condensing, combination boiler used in an English winery

Operating temperatures for steam production are much higher, up to 200ºC as opposed to 80ºC from a traditional centralised boiler or pressure washer. However, steam at 200ºC at atmospheric pressure is superheated and this dry steam, with perhaps 5% relative humidity, can transfer heat very rapidly reducing the time needed to clean and sterilize equipment. Steam is not applicable for all cleaning activities in the winery and is typically used in the bottling line, barrel cleaning and hydration and tank sanitation.

Figure 2.67: Electrical 'resistance' steam generator

In areas where water quality is poor, particularly in rural areas where water may be taken directly from a borehole source, energy input may not only be necessary in extracting the water but may also be necessary in improving the quality of the water. The overall energy demand, whilst continuous, is relatively small for English wineries and does not represent a huge proportion of energy usage in the winery.

Hot water production
Boilers are the heart of the hot water generation system, and substantial efficiency improvements can be attained. English wineries used hot water for a range of cleaning activities and some heating for vinification processes (malolactic fermentation or wine pre-heating before bottling). Some of the most important considerations are:

- Boiler location. Locating the boiler(s) close to the main hot water load will have a significant impact on energy usage. The distribution of hot water leads to heat losses from the pipework. Although not always possible, a well-maintained, properly located hot water boiler and distribution network can reduce losses attributed to distance by 5%.
- Correct boiler selection. Selecting the correct size, type and configuration of boiler is of the utmost importance. Correctly designing the boiler system to meet the demand load is based on many factors, including fuel, temperature and pressure, operating mode, distribution configuration, base load and modularisation. If hot water demand varies widely over time, it may be beneficial to spilt from one main boiler and use a modular 'cascade' format with a number of smaller boilers, thereby always maintaining boiler operation near its peak efficiency at full load. The energy savings for properly sized boilers is estimated to be 8% of boiler fuel use.
- Consider Combined Heating and Power where appropriate (see section 2.6.9)
- Simple boiler maintenance can ensure that all components of the boiler are operating at peak performance. Fouling of the fireside of the boiler heat exchange surfaces should be controlled.
- Excessive flue gas flow will result in additional wastage reducing the amount of heat transferred to the heated medium. Flue gas monitors maintain optimum flame

temperature and monitor carbon monoxide (CO), oxygen and smoke, by controlling the amount of inlet air.

- Optimise high/low firing sequences to reduce ignition purge cycles.
- Apply weather-compensated boiler temperature control if feasible.
- Reduce boiler blow-down levels and frequency to a minimum.
- Reduce the amount of inlet air. More air introduced to burn the fuel will result in greater wasted heat in the flue. Air supply should be slightly more than the ideal stoichiometric fuel/air ratio. 15% is thought adequate
- Using improved boiler insulation (on older boilers) can achieve significant savings.

In addition to good boiler operation, the distribution network must be properly maintained. Any leaks should be repaired immediately and all hot water pipework must have adequate insulation, considering the use of more insulating material or using the best insulation material available.

2.6.5 Winery moving machinery

Transportation in the surveyed English wineries, broadly relates to fork trucks although some other lifting equipment was observed. Fork trucks can be classified according to the engine type, work environment, operator position and specific characteristics, such as tyre type or maximum grade. In the modern winery, typically there may be a range of different types but most will have electric units with cushion or pneumatic tyres and internal combustion units (LPG or diesel) with cushion or pneumatic tyres. Electric aerial aisle lifts and powered hand trucks and pallet jacks may also be used.

Approximately 7% of all energy used was related to transportation machinery in the winery. Fork trucks are used extensively throughout the large English wineries to load and unload vehicles, move bins and tanks, stack barrels and shift equipment, supplies and finished products. Just over 47% of the wineries surveyed used a fork truck or dedicated mechanical lift equipment, of which four wineries utilised an LPG truck and a further winery had an LPG truck with an electric truck. Two wineries had a diesel truck only and another had a diesel and electric truck. Only one winery had an electric truck only. None of the small wineries visited had a fork truck.

In a study by Smyth (2010) the energy used by fork trucks was divided been the propane and electrically powered vehicles. The energy used was calculated to be 0.05 kWh (fuel equivalent) per litre of wine produced for the propane units (2 of) and 0.01 kWh per litre of wine produced for the battery powered units (4 of). In the study by Neelis et al (2008), forklifts were assumed to use approximately 0.028 kWh (fuel equivalent) per litre of wine produced. In the current study, 0.037 kWh (fuel equivalent) per litre of wine produced was expended by winery moving machinery in English wineries.

The choice of fork truck is very much dependent upon the winery, but in general, electric forklifts are clean, quiet, compact and nimble with charging constraints, LPG forklifts are best performers and have indoor/outdoor flexibility whilst diesel forklifts are best outdoors and on average, cheaper to run. In terms of energy improvements, good housekeeping and common sense can yield the greatest savings. Reducing the number of fork trucks within a facility can reduce energy wastage with fewer units on standby. By the same token, electric fork trucks do not idle when the truck is in park or neutral so they can have a higher operating efficiency over fuel based trucks when they are on standby.

2.6.6 Miscellaneous

Miscellaneous is a very broad category that includes a range of equipment necessary to provide a suitable working environment for the production processes and includes monitoring devices, security devices, shutter doors, insect control and laboratory equipment. In a wider context miscellaneous also covered a range of equipment used is the wider ancillary activities used in the English winery, comprising: PC, laptops and general office equipment (printers, fax machines, Wi-Fi and routers, telephones, laminators, shredders, photocopier), audio-visual equipment, cash registers, credit card readers, hand dryers, microwaves, bottle coolers and dishwashers. Just under 3% of energy used in production activities with the English winery was covered by miscellaneous, equal to 0.019 kWh per litre of wine produced.

Figure 2.68: UV insect killers

The vast array of different equipment and processes covered by this title makes it difficult to itemise every single method to reduce energy consumption. In many cases, after selecting the most energy efficient equipment available, good common sense in its operation should be exercised, for example, switching off when not in use. A number of wineries maintained tank sensory/monitoring equipment on even when the tank was not in use; a small 3 Watt unit maintained 24 hours a day, all year can equate to over 26 kWhs per year. Many wineries had UV insect killing units (figure 2.68). Whilst absolutely necessary at certain times of the year and in specific locations, significant savings can result if they are only switched on when needed.

2.6.7 Winery juice/wine pumping, filtration and mixing

Juice/wine pumping, filtration and mixing activities account for approximately 2% of the energy used in the English winery (excluding requirements for refrigeration, HVAC and water pumping), equating to almost 0.012 kWh/litre wine produced. It is sometimes claimed that a winery design based on gravity can reduce the need for pumping and thus the associated energy. Given the fact that this study has shown that juice/wine pumping, filtration and mixing activities in energy terms are so small, there is potentially little to be gained by adopting a gravity design if the initial capital costs (and embedded energy cost) are excessive.

A variety of pump formats are available to meet the requirements of different winery applications. In basic terms, wineries use either centrifugal or positive displacement pumps. Figure 2.69 illustrates the classification of pumping systems used in winemaking. It is worth noting that the initial capital cost of a pump could be as high as 5% of its total lifetime cost whilst the lifetime cost of operating the pump (including maintenance) may be about 95% of the cost. Selecting the correct pumps (and most efficient pump available) is therefore the most important decision to be made in a new winery. Replacing pumps in an existing winery with new, more appropriate, higher efficiency pumps can save up to 10% in energy consumption.

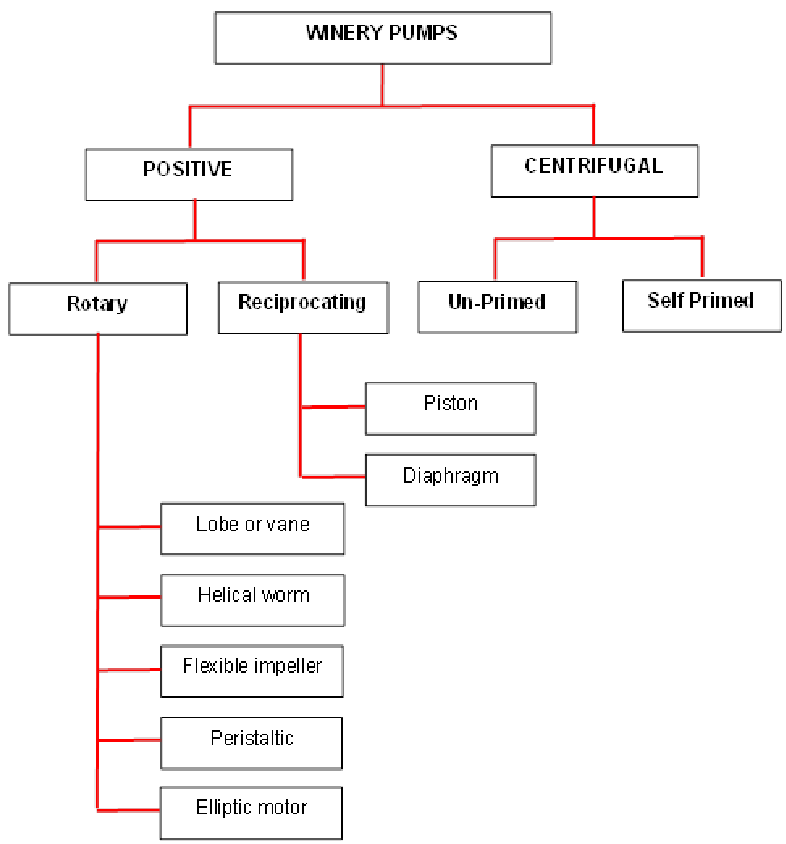


Figure 2.69: Classification of pumping systems used in winemaking
(adapted from Boulton et al 1996)

Increasing pump efficiency can be achieved in three ways:

- Reduce operational use where appropriate to do so. Holding/buffer tanks can be used to equalize the flow over the production cycle and bypass loops and other unnecessary flows should be eliminated. Where possible reduce peak pumping loads as this can lead to a reduced pump size and thus energy consumption.
- Reduce friction where applicable, for example, correct sizing of pipes/fittings or the use of surface coatings/polishings may reduce the friction loss. It is estimated that coating pump surfaces can yield efficiency savings of 2 to 3% over uncoated pumps.
- Adjust the system 'resistance' curve so that it is closer to the best efficiency point (BEP) on the pump curve

The incorrect sizing of pumps and pipes leads to a mismatch in their operating characteristics. Correcting for pump oversizing can save between 15 to 25% of electricity consumption for pumping. Similarly, the correct sizing of pipes can avoid unnecessary losses. The pipework diameter is selected based on the best installation compromise; cost versus flow velocity and selected internal pipe diameter for the given application. Some studies have estimated that retrofitting pipe diameters can save 5 to 20% of their energy consumption. Other considerations to reduce energy use include:

- Using multiple pumps is a cost-effective and energy efficient solution for meeting variable pumping loads (figure 2.70), particularly in a static head dominated system.
- If a large differential pressure exists at the operating rate of flow (indicating excessive flow), the impeller (diameter) can be trimmed so that the pump does not develop as much head.
- Variable Speed Drives (VSDs), as previously discussed, permit better match speed to load requirements for motor operations. Matching the speed of the pump to the load requirement will result in lower energy usage as energy use is approximately proportional to the cube of the flow rate. Small reductions in flow that are proportional to pump speed will therefore yield large energy savings. Throttling valves should always be avoided.
- Replacing belt drives with direct couplings may save up to 4%, giving a simple payback period of 0.8 years.
- A good control strategy to shut off unneeded pumps or reduce load until needed will yield immediate savings. Remote controls enable pumping systems to be started and stopped more quickly and accurately when needed, and reduce the required labour.

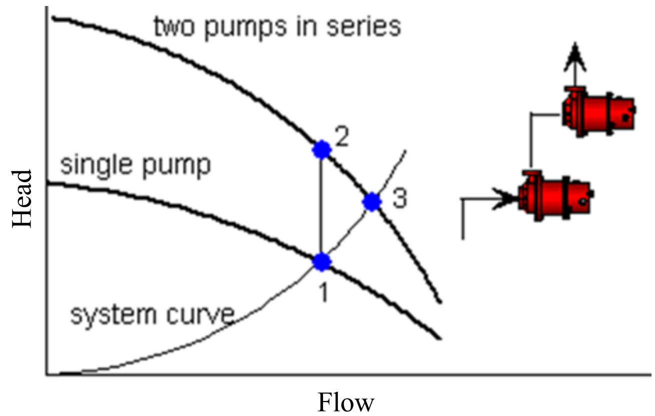


Figure 2.70: Multiple pump options

Maintenance and monitoring of pumping systems, as with all winery equipment, will always be of benefit. Monitoring in conjunction with maintenance can be used to detect problems and determine solutions to create a more efficient system. Proper maintenance includes the following:

- Replacement of worn impellers.
- Bearing inspection and repair.
- Bearing lubrication replacement.
- Inspection and replacement of packing seals.
- Inspection and replacement of mechanical seals.
- Wear ring and impeller replacement.
- Pump/motor alignment check.

2.6.8 Grape processing

Energy related to grape processing accounts for less than 1% of the all the energy expended in English wine production, equivalent to 0.008 kWh/litre wine produced. Grape processing includes all equipment and processes involved in the receiving, crushing and pressing of grapes (+ any compressed air energy requirements). Pressing activities constitute the largest energy cost within this classification. The vast majority of wineries utilised some form of mechanical/pneumatic pressing process. Five percent of the surveyed wineries utilised a Coquard wine press using a hydraulic ram and gentle horizontal movement to break the press cake. A further 5% had a horizontal plate press with a membrane/bladder press, but 74% relied on membrane/bladder presses only. Willmes pneumatic presses were the most popular bladder/membrane press brand by far, with 9 presses being utilised by the wineries surveyed. Vaslin, Enovent, Defranceschi and SKRLJ were utilised in a couple of wineries. Just 16% used hydraulic water basket presses (figure 2.71), requiring no energy input whatsoever.

Figure 2.71: Hydraulic water basket presses

Many of the energy saving measures related to motors and pneumatic compressed air systems can likewise be applied to grape processing equipment.

2.6.9 Other Energy Considerations

Electricity

Many methods to use electrical energy use in the winery have already previously been discussed, such as good lighting design or motor selection. There are, however, a number of other improvements that may be considered appropriate for the modern winery environment:

- Use the most efficient transformers. Larger wineries may have on-site transformers to produce low voltage. Older transformers can have conversion losses of up to 3% of the total supply. New, energy efficient transformers can reduce these losses by roughly 30%.
- Ensure good phase voltage balancing. Equipment such as motors and their controllers will not operate reliably on unbalanced voltage in 3-phase electrical systems. Ideally, the difference between the highest and the lowest voltages should not exceed 4% of the lowest voltage. Greater imbalances may cause overheating of components, especially motors, and intermittent shutdown of motor controllers.
- Consider Power Factor correction. PCs, variable speed drives, induction motors and other equipment can lead to poor power quality. Harmonic distortion can lead to reduced efficiency (through increased generation of heat) while heavily distorted harmonics may result in equipment damage. Installing power factor correction systems may reduce losses. Linear loads with low power factor (such as induction motors) can be corrected with a passive network of capacitors or inductors. Non-linear loads, such as VSDs, distort the current drawn from the system. In such cases, active or passive power factor correction may be used to counteract the distortion and raise the power factor. The payback period of installing power factor correction systems on the capacity and may vary between 12 and 18 months.
- Electronic controls to turn off equipment. Electronic controls can be as simple as on/off switches to be switched off during non-operating hours. Simply turning equipment off manually may lead to immediate savings of up to 10%.
- Power management for office and ancillary equipment. Equipment such as PCs, printers, audio-visual equipment, etc. whilst small in load for most wineries, are often left on during periods when they are not used. However, much of the modern equipment now being sold has integrated power management software which can turn off (or standby-mode) equipment after a set period of time without use. A monitor turned down uses only 10% of the energy of a monitor without power management options installed.
- Standardisation of equipment and components is an important issue in facilities with significant levels of mechanical equipment. Having identical equipment (manufacturer, model, etc.) to carry out similar tasks creates user familiarity which helps foster a greater understanding of its operating characteristics and thereby higher performance levels. In addition, standardised equipment permits interchangeable consumables (filters, belts, seals, etc.) which can be purchased and stored in bulk to reduce down time if waiting for one-off replacement components.
- Future proofing electrical installations (and other services) using modular or bolt-on formats can permit facilities to adapt or modify existing configurations very quickly and easily to accommodate new production methods or more efficient equipment.
- Consider rewiring cables if possible. Using the minimum regulation size means greater

losses, higher current resulting in increased heat. If we consider the example of a 7.5 kW motor, operating for on average 5,600 hours per year at a 5.0 kW loading, with 30m cable run from the transformer to the motor. Using a standard efficiency transformer and motor with a $6mm^2$ twin/cpc cable the approximate losses are 998 Watts. Utilising a low loss transformer and high efficiency motor with a $16mm^2$ twin/cpc cable the approximate losses are 567 Watts.

Combined Heat and Power (CHP)

Combined Heat and Power is a viable option for many wineries. The existence of simultaneous power and heating (hot water) loads make CHP an attractive option. A CHP system is primarily a prime mover with good heat recovery equipment. For most wineries the most suitable prime movers are traditional reciprocating engines (e.g., diesel engines) which convert fuel to shaft power, which then spins a generator to produce electricity and an integral cooling jacket to recover by-product heat. Micro-turbines offer a more advanced CHP system, but these are not as common.

A significant number of English wineries have on-site diesel generators, producing direct electrical supply (3 phase or single phase) and backup. It would not require a significant amount of foresight to realise that the potential for utilising the waste heat (in a CHP format) would be substantial in these facilities. Recent developments in engine design have increased power efficiency and reliability, while dramatically reducing the emissions of these engines. These new designs can use a variety of liquid and gas fuels, including natural gas. The electrical efficiency of most engines varies from 20 to 35% depending amongst others, upon size, load and age. Total CHP system efficiencies can be as high as 80%, provided that all the generated power and heat is collected and used effectively.

Tri-generation

Tri-generation is the next obvious step for a winery. As with combined Heat and Power, tri-generation is a viable option for many wineries. The existence of simultaneous power, heating (hot water) and cooling loads make tri-generation an attractive option. Tri-generation is quite simply CHP with adsorption or absorption refrigeration systems that utilise generated heat for cooling. In the absorption refrigeration cycle, no compressor is necessary as the vapour compression is created by the characteristics of the refrigerant and carrier elements. Ammonia/water is most common vapour/liquid solution, requiring waste heat at about 120ºC or higher to drive the system. Adsorption units can be driven by lower temperatures, typically around 90ºC. These systems do not use ammonia or corrosive salts, but use silica gel. Figure 2.72 depicts a novel NH_3/H^2O absorption refrigeration unit, used to produce chilled water production and direct air cooling in a winery in Styria, Austria, along with heating and power generation from solar, wood chip furnace and Stirling engine. The thermal performance of both adsorption or absorption systems is similar with a COP (Coefficient of performance) between 0.68 and 0.75, and capital costs are comparable.

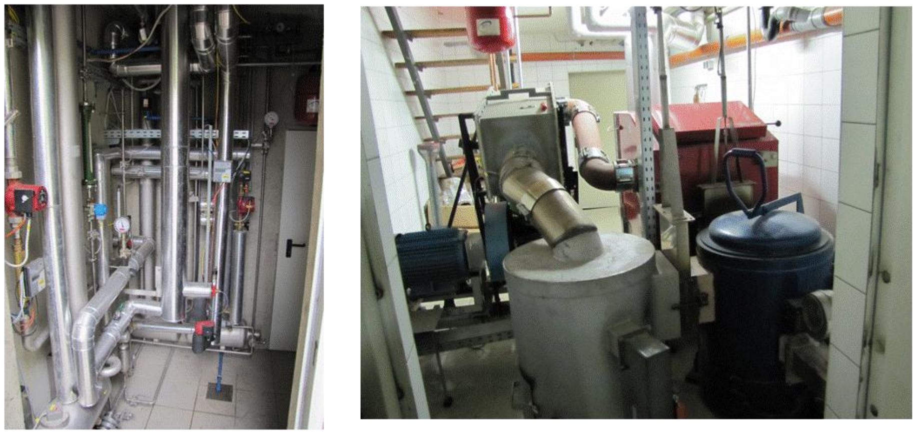


Figure 2.72: A 10kWc NH_3/H_2O absorption refrigeration unit (left) and 50 kWth wood chip furnace connected to a 3 kWel Stirling engine (right)

A tri-generation system should be optimized based on the demand for cooling and heating, based on a detailed understanding of the winery's energy consumption. As with CHP design, the system should be designed to meet the base electrical load with cooling (and heat) used directly or indirectly via storage. The peak cooling demand during the harvest period will be met with additional cooling equipment.

REFERENCES

Anon (2010a) Winery Energy Management Project: Cape Mentelle Audit. Grape and wine research and development corporation, Perth, Australia

Anon (2010b) OIV summary on the global situation of the vine and wine industry in 2009. 33rd World Congress of Vine and Wine (June 2010), Tbilisi, Georgia

Boulton R, Singleton V et al (1996) Principles and practices of winemaking. Chapman and Hall, New York, USA

Chuine I, Yiou P, Viovy N, Seguin B, Daux V, Le Roy Ladurie E (2004) Grape ripening as a past climate indicator, Nature, Vol. 432

CIBSE (2004) Guide F: Energy Efficiency in Buildings. CIBSE, London, UK

Colman T and Päster P (2007) Red, White, and "Green": The Cost of Carbon in the Global Wine Trade. American Association of Wine Economists (AAWE) Working Paper No. 9, New York, USA

Coquard Presses (2012) Personal correspondence with Jean Pierre Masset, Coquard Presses, France

Cotana F and Cavalaglio G (2008) Poly-generation From Vineyards Pruning Residues in an Umbrian Wine Company. 16th European Biomass Conference & Exhibition, Valencia, Spain

DEFRA (2003) Guidelines for the Measurement and Reporting of Emissions by Direct Participants in the UK Emissions Trading Scheme (June 2003).

DOE/EIA (2010) United States Department of Energy's Annual Energy Outlook 2010. Energy Information Administration. Report Number: DOE/EIA-0484(2010).

Dugger P (2008) Emerging Green Trends for Wineries - Energy Management - Towards Climate Neutrality through Efficiency, Generation and Carbon Offsets. PG&E: The green wine summit, Hyatt Vineyard Creek, Santa Rosa, USA

English Wine Producers (2011) UK Vineyards Celebrate Record Breaking Production Figures. Press Release: 4th May 2011, The English Wine Producers Trade & Press, London, UK

English Wine Producers (2012) English Wine Production Statistics (Information supplied by Wine Standards Branch (Food Standards Agency)), The English Wine Producers Trade & Press, London, UK

Forbes SL, Cohen DA, Cullen R, Wratten SD and Fountain J (2009) Consumer attitudes regarding environmentally sustainable wine: an exploratory study of the New Zealand marketplace. Journal of Cleaner Production, Vol 17, pp 1195–1199

Forsyth J, Oemcke D and Michael P (2008) Greenhouse Gas Accounting Protocol for the International Wine Industry: Version 1.1. Provisor Pty Ltd, Hartley Grove, Urrbrae, South Australia.

Good Practice guide (1998) GPG 238 heat recovery from air compressors. ETSU, Oxfordshire, UK

Karousou N, Stefanou F et al (2007) Energy and economic potential assessment for SAHC plants in selected agro food sectors. ALTENER- Renewable heating and cooling EIE/07/224. SAHC Project Promotion of Solar Assisted Heating and Cooling

Laurence Gould Partnership (2012) Greening UK Wine – A sustainability policy for the UK Wine Industry. United Kingdom Vineyards Association, PO Box 284, Cirencester, England

Neelis M, Graus W et al (2008) Amethyst Report: Benchmarking and self-assessment tool for wineries. ECOFYS, Utrecht, Netherlands

Point EV (2008) Life cycle environmental impacts of wine production and Consumption in Nova

Scotia, Canada. Master of Environmental Studies, Dalhousie University, Halifax, Nova Scotia, Canada.
Rosenblum J (2007) Energy and water efficiency at Sonoma Wine Company. Rosenblum Environmental Engineering, Sebastopol, California, USA
Smyth M (2010) Solar Energy in the Winemaking Industry. Global Research Report, Award Ref: 10177/177, The Royal Academy of Engineering, London, UK
Van der Zijpp S (2008) Improving energy use in the wine industry. Membership pack, Sustainable Winegrowing New Zealand, PO Box 845, Blenheim 7240, New Zealand