

Module 4: Historical Energy Assessment

Learning Objectives

After completing this module, you will be able to

- Identify data sources for the assessment of the building's energy performance;
- Describe the instrumentation used for energy audits;
- Analyse the energy tariffs that apply to the building;
- Correlate energy consumption to building operational parameters and weather.

4.1 Measurement and Data Collection

4.1.1 Data Sources

Part of designing the audit plan is the identification of data sources. Many sources of existing data can be utilized, both within the organisation and external to it. Kinds of data and their sources typically include the following:

- **Historical energy consumption data:** invoices for purchased energy of each type should normally be available from the finance department for the building owner;
- **Metered energy consumption:** often the utility that supplies electricity will be able to provide historical data on demand and consumption;
- **Building configuration:** the auditor will need to know building dimensions as well as the layout of electricity, steam, domestic hot and cold water systems, along with the location of any existing meters;
- **Weather data:** as discussed later in this module, the correlation of energy consumption to weather is a step in the analysis of building performance; average temperature data or, perhaps, calculated degree-day data, is available from the weather office in Pretoria.
- **Energy system nameplate data:** the design energy characteristics of the equipment in the building can usually be taken from nameplates; however, it is important to realize that the actual operating characteristics may be quite different depending on the age, condition, and loading of these systems;
- mechanical, electrical, architectural plans and specifications;
- building automation system (BAS) documentation including control schematics and sequences of operation;
- maintenance logs;
- key plans (floor plans),
- contact information for building operational personnel or service contractors.

Once available data has been identified, the auditor is in a position to determine what additional data needs to be collected by direct measurement.

4.2 Instrumentation for Energy Audits

4.2.1 Introduction

This section describes the instrumentation and measurement techniques relevant to energy audit activities. A brief review of measurement principles is provided. Finally, a set of useful, relatively easy to use and readily available instruments have been selected from the toolboxes of experienced auditors and are presented in practical terms. Basic instrument types and usage are described along with sample specifications, sources and tips for effective use. While comprehensive for the type of energy audit described in this manual, the list of instruments can be supplemented by the more advanced auditor with more advanced sensors and recording devices.

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It is important that an energy auditor has a basic understanding of measurement techniques and instrumentation in order to be knowledgeable in the purchase or rental and use of the equipment. Both the correct instrument and its correct use are fundamental requirements for obtaining useful measured data.

4.2.1.1 Safety First

Measurements upon any physical system or process should always be undertaken with due regard to safety procedures by persons trained and familiar with the specific equipment and processes involved. Measurements of electrical energy use, amps, volts and watts etc. are generally made upon live equipment and conductors and should only be undertaken by properly trained and qualified technical staff. Under no circumstances should live electrical equipment be opened by unqualified persons.

4.2.2 Understanding Measurement for Energy Auditing

Ordinarily, an energy audit of the type discussed in this manual takes place over a limited timeframe, often days and weeks, likely not more than a month in length. During the course of the audit measurements will be taken to form the basis for the many energy calculations involved in developing energy inventories, profiles and eventually estimates of energy savings. Most audit measurements are short-term records taken instantaneously or over a short time interval, with recording instruments. On the other hand, most savings calculations are made on an annual basis; most organizations want to know what the energy management measures will save them next year.

While the accuracy of any of these measurements is important, as discussed in the next section, just as important is the relevance of these short term audit measurements to the conditions that exist over the long term, that is, the annual period on which savings calculations are being made. While it may be easy to accurately measure the power consumption of an air compressor motor with a handheld power meter, and then multiply by the hours of operation per year to determine annual energy consumption, we need to consider whether the reading that we took is representative of the power consumption tomorrow, next week or next month.

The most accurate instantaneous measurement may only be accurate to +/- 50%, on an annual basis. Clearly, care must be exercised when extrapolating short term measurements to longer term results. A useful technique in avoiding such errors is to attempt to take measurements during periods that are representative of the operation of the particular equipment involved. Tips for taking valid and representative measurements with each instrument are included in the following sections.

To some extent, the energy balance techniques presented in this manual provide a check against gross errors. For example, power measurements taken on equipment must sum to the total load as registered on the utility's demand meter and recorded on the bill. Likewise, the energy consumption derived from the application of operating hours must sum to the total metered energy on the bill. While this is not a guarantee against this type of error, looking for these balances also forces the auditor to think in terms of long term conditions.

4.2.2.1 Measurement Accuracy

The accuracy of the measuring device (instrumentation) and the proper use of the instrument are two items that can affect measurement accuracy. Before purchasing or leasing instrumentation it is important to determine how accurate the measurement needs to be and to select instrumentation and measurement strategies that meet those needs. One can generally expect to pay more for more accurate instrumentation, but more expensive and accurate instruments often demand more careful and time consuming measurement techniques.

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For specialized and "once only" measurements it may often be beneficial, both in terms of accuracy and overall cost, to engage competent independent technicians to do the measurement.

When evaluating instrumentation for purchase or lease, it is useful to know how different manufacturers define the accuracy of their equipment. Some common ways of defining accuracy are:

- percentage of full scale,
- percentage of actual reading value, a "resolution"; this is common for instruments with digital read out and is often stated as the number of digits.

In most cases, particularly for quality instruments, the stated accuracy will be for a particular set of circumstances; e.g. the type of wave forms or frequency might be stated for electrical measurements. Often some indication of loss of accuracy that will occur when the instrument is used outside the particular circumstances will be given.

For the purposes of the macro energy audit, the requirement for accuracy may not be extremely demanding. As stated previously, a highly accurate measurement today may only have an overall accuracy in the long term that is very low. Accordingly, the auditor may redirect effort and expense from the purchase and use of highly accurate instruments to better interpretation of less accurate data over long term patterns.

4.2.3 Spot and Recording Measurements

Although many of the measurements taken in any energy audit are instantaneous or "spot" measurements there may be an opportunity to perform short term recording measurements. Recording measurement, applied over carefully selected time intervals can provide far more representative data for long term calculations.

As an example, the auditor may have noted from spot measurements of an air compressor that its "idle" power, consumed when not supplying an air demand, was 70% of expected full power. This suggests that application of a controller to shut down the compressor when not required might be a good energy savings opportunity. But, does this condition exist for a significant period of time? Plant staff report that the compressed air demand is "fairly steady". In this situation the use of a recording power meter, taking minute by minute readings for 48 hours, over the course of a full production day and possibly one shutdown day, could provide a better picture of the situation. The recording power meter is an extremely valuable tool to the energy auditor.

Other useful recording tools, often called data loggers, include:

- Temperature logger
- Illumination logger
- Occupancy logger
- Event logger
- General purpose data logger

4.2.4 Useful Features of Digital Instrumentation

For auditing and many other purposes, digital meters (DM) are replacing conventional analogue instruments because of lower cost and ease of use. Their accuracy is normally more than adequate for most auditing purposes. Some features that are notably useful include:

Multiple measurements – integrated instruments that can measure and in some cases record two or more parameters such as temperature, humidity, on/off states, illumination levels and one or more general purpose analogue inputs (see below), for other sensors.

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Reading Freeze Function – facilitates readings where the display cannot be read as the measurement is taken.

Display Invert – may ease reading of the meter in difficult locations – tachometers often feature this capability

Analogue Output – a standard analogue signal (0-10V, 4-20 mA etc) proportional to the reading which can be used with a strip chart recorder or general purpose data logger to provide a recording function.

4.2.5 The Auditor's Toolbox

In the following sections include details of the instruments commonly found in the energy auditors toolbox:

- Electric Power Meter
- Combustion Analyzer
- Digital Thermometer
- Infrared Thermometer
- Psychrometer (Humidity Measurement)
- Air Flow Measurement Devices
- Tachometer
- Ultrasonic Leak Detector

In addition to the instruments there are a few other items that have been found to come in handy:

- A camera – “a picture is worth a thousand words”
- Binoculars and a small flashlight – for reading nameplates
- Duct tape & Tie Wraps – for securing recording meters
- Multi- screw driver, adjustable wrench and pliers
- Tape measure
- Bucket and stopwatch – for gauging water flows to drain.
- Safety Glasses, Gloves & Ear Plugs
- Caution tape – for alerting others to the presence of recording meters.

4.2.6 Electric Power Meter

To the energy auditor, electric power measurement instruments are some of the most powerful and useful tools available. With existing measurement and data recording technology, a modest investment will provide a wealth of information. Electrical power and energy measurements provide an operational fingerprint of the many systems and pieces of equipment in a facility. They show clearly where and how electrical power and energy is used and provide insight into how equipment and system consume other forms of energy – typical audit applications are provided below.

With today's technology there is no need for an auditor to carry separate volt, amp and power factor meters in order to be able to measure electrical power in watts. The modern portable wattmeter provides all of these measurement functions and more integrated into one package. This section describes selected types of wattmeters, applicable to energy audits, incorporating all of these measuring functions. For the reader requiring knowledge of basic electrical measurements, a technical overview of current, voltage and power factor is provided in the energy basics section. Further information can be found in any basic electricity textbook.

As stated previously, any measurements with these types of instruments should only be undertaken by personnel trained and authorized to work on live electrical equipment.

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Handheld Single Phase Digital Wattmeter

The single phase wattmeter will measure voltage via two contact probes, and current with the use of a clip-on current transformer, commonly referred to as a current clamp. A typical meter is illustrated in Figure 4.16. The configuration shown in the left side of Figure 4.16 is capable of metering 600volt systems up to a maximum current of 200 amps. Using the flexible current transducer shown on the right had side of Figure 4.16 this type of meter can meter currents from 30 to 3000 amps. The particular metering shown also has the facility to record or log up to 4000 data points for short term surveys or profiles. While spot measurements only require instantaneous contact with conductors for voltage readings, the recording measurements require the use of optional alligator clips as shown in Figure 4.1.

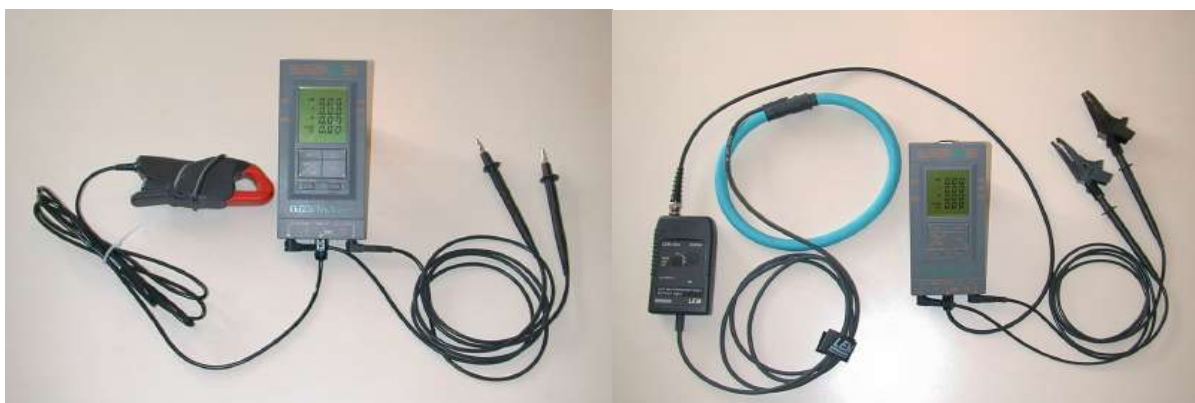


Figure 4.1: Handheld Wattmeter

Primarily intended for measurements in single phase circuits, these meters often provide the functionality required to perform measurements on balanced three phase power systems. Typical connections are illustrated in Figure 4.2.

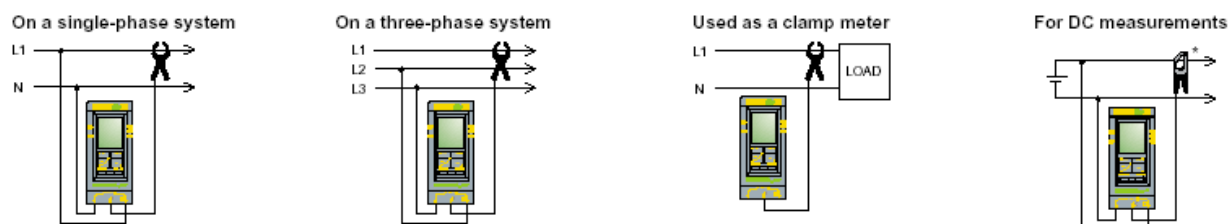


Figure 4.2: Typical Connection for Single Phase Wattmeter (Courtesy: Elcontrol® Energy Net)

Three Phase Digital Wattmeter

For true measurements on three phase systems, depending upon whether the system is 3 or 4 wire, 2 or 3 phase currents, and three phase voltages must be measured. Figure 4.3 shows a three phase wattmeter and a typical connection diagram.

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Figure 4.3: Three Phase Wattmeter and Typical Connection
(Photograph: Elcontrol® Energy Net)

Applications

Development of Load Inventories – as detailed in the Energy Inventory section, the handheld wattmeter can expedite collection of individual load kW values.

Demand Profiling of a Service Entrance, Sub-Station or MCC – for developing plant, building or system wide demand profiles as detailed in the Demand Profile section. This will require the use of a three phase meter, often with optional current transducers, similar to those shown in Figure 4.3, to meter the large currents in the buss bars and conductors.

Process System or Equipment – it may be possible to isolate a group of loads specific to a particular system, equipment, manufacturing cell or plant process.

Individual Load Metering – for motor loads, either one or three phase, a single phase wattmeter may be deployed for either spot or recording measurements. Using the recording function, typical operating profiles of fans, pumps and compressors can be developed.

Electric Process Characterization – electrical energy consumption data can be measured and correlated to production data over a sample interval to characterize the consumption patterns of a process. This is particularly useful for process such as electric furnaces, dryers and kilns. Depending upon the configuration of the equipment and power supply it may be possible to conduct such a survey with a single phase power meter – the three phase meter will work in most situations.

Measuring Consumption of Office Equipment – using a simplified power meter for determining energy consumed over a typical period of operation as illustrated in Figure 4.4



Figure 4.4: The Brultech ECM1200 Measuring Computer Monitor Energy Consumption

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Sample Specifications

For Handheld Wattmeter

- Volt, Amps, Watts, VAR, VA, W, Hz, kWh (import/export), kVARh.
- All measurements are true RMS.
- Memory adequate for recording multiple measurements over a varying interval.
- 1% accuracy - including clamp error.
- Backlit LCD display
- Battery powered

For Three Phase Wattmeter

- Portable Power Meter for both single phase and 3 phase systems, providing measurement of true RMS values for up to 33 parameters including Volts, Amps, Watts, VAR, VA, W, Hz, kWh (import/export), kVARh.
- 1% accuracy - including clamp error.
- High-contrast backlit LCD display
- At least 1MB on-board memory for data storage over extended survey periods including waveform capture for current and voltage.
- Supplied complete with CTs, voltage leads and all accessories in a strong carry case.
- Download to PC via high-speed serial link.
- PC (Windows) based software for data download, analysis and export to spreadsheets.
- Fully programmable for all CT/VT ratios, star/delta/single phase connection and power integration period.
- Dual voltage power supply 230/110VAC with internal rechargeable back-up battery.
- On-board clock/calendar.

Useful Features

There are many features available on these types of meters beyond the basic power measurement functions. While handy, these additional functions are not entirely necessary. Some which have been found to be useful for energy auditing activities are listed below.

For Handheld Single Phase Wattmeter

- Measurement and analysis of power quality parameters including harmonics.
- DC measurement with optional Hall Effect sensor.
- Automatic recognition of clamp type
- PEAK feature captures max current/power values.
- MEM function provides data hold and allows real time comparison of new readings against stored values

For Three Phase Wattmeter

- Stand-alone battery powered function to allow installation in, and safe closure of electrical cabinets.
- Measurement and analysis of power quality parameters including harmonics.
- Suitable for DC measurement (via optional DC clamp).
- Optional inputs for recording of other parameters such as temperature.

Tips for Effective Use

- **Validate readings at time of collection** – when deploying meters for recording ensure that the instantaneous readings are reasonable. Many data collection errors are result of a misconnected meter and can be avoided at connection time. Checking readings against any existing metering such as panel meters or utility meters can provide quick validation of readings. Unexpectedly low or high power factor readings are a common

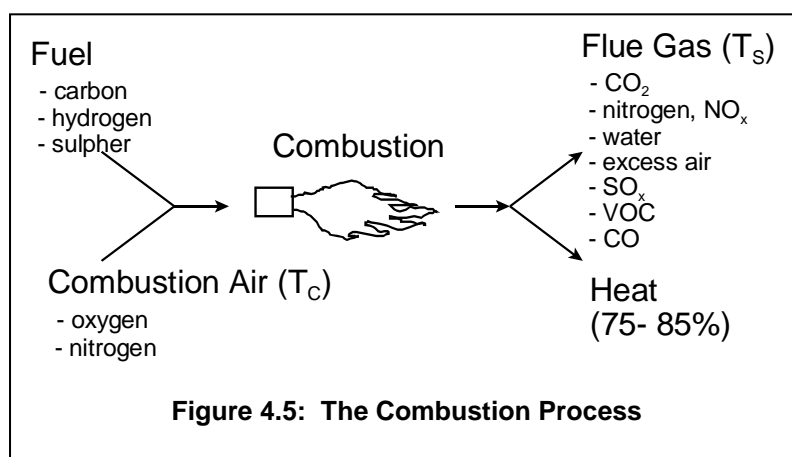
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clue to incorrect connections. Power readings may appear valid while power factor will not.

- **Utilize as short an integration or averaging time interval as possible for recording power and energy readings** – ideally, one minute intervals. Power meters will typically average the measured values over the recording interval. Information is lost in the averaging process. Shorter intervals provide more electrical fingerprints of loads, simplifying interpretation of the resulting profiles.

4.2.7 The Combustion Analyzer

Modern combustion analyzers are portable electronic instruments used to measure the combustion efficiency boilers, furnaces or other equipment with fuel combustion systems. Figure 4.5 illustrates the essential elements of the combustion process. The primary objective of combustion analysis is to ensure the optimum ratio of air to fuel is being utilized. Excess air will appear in the flue gases and carry away heat that could otherwise be used. Insufficient air will lead to incomplete combustion often indicated by significant levels of Carbon Monoxide (CO) in the flue gases.



The determination of combustion efficiency is made from a multiple measurements including flue/stack temperature and the composition of stack gases - typically Carbon Dioxide (CO₂) or Oxygen (O₂). Often instruments measure a number of other parameters indicative of combustion system performance, as described below.

Instrument Description

All electronic combustion analyzers integrate a number of measurement functions into one unit, which is often battery powered and uses a digital display and keypad as a user interface. A basic analyzer will measure:

- Flue/Stack Gas Temperature
- Combustion Air Temperature
- Oxygen (O₂)
- Carbon Monoxide (CO)



Figure 4.6: Electronic Combustion Analyzer

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The user selects from a display menu the fuel being used in the combustion system. Based upon an internally programmed algorithm containing data regarding fuel composition, the analyzer will then compute and display the combustion efficiency, along with a determination of excess air and carbon monoxide (CO) level.

A typical combustion analyzer is shown in Figure 4.6. This unit is appropriate for testing of boilers, plant heating equipment and a limited set of process combustions systems. In addition to the parameters measured above this unit can also measure stack draft – the pressure in the stack/flue driving the flow of hot gases from the combustion system.

Applications

Combustion analyzers can be used in a wide variety of combustion equipment, fired by gas, oil, coal and a number of other fuels including wood. Applications include but are not limited to:

- Boilers
- Unit heaters
- Hot water heaters
- Heating furnaces
- Process furnaces
- Process ovens
- Kilns
- Dryers
- Ladle pre-heater
- Material preheaters

For applications outside of building heating equipment, the reader is encourage to consult with the suppliers of these instruments to ensure selection of appropriate instrument ranges and functions.

Sample Specifications

- Measure O₂, CO₂, efficiency, excess air, draft and CO (325-1 only)
- Large, menu-driven display
- Optional NO_x measurement
- TEMPERATURE MEASUREMENT
 - Measurement Range/Resolution: -40 to +1112°C / 0.1°C
 - Accuracy: ±0.5°C
 - Sensor: Thermocouple Type K
- DRAUGHT/PRESSURE MEASUREMENT
 - Measurement Range/Resolution: ±16 in H₂O / 0.1 in H₂O
- GROSS/NET EFFICIENCY
 - Measurement Range/Resolution: 0 to 120% / 0.1%
- O₂ MEASUREMENT
 - Measurement Range/Resolution: 0 to 21 vol.% / 0.1 vol.%
 - Accuracy: ±0.2 vol.% absolute
- CO₂ MEASUREMENT
 - Measurement Range/Resolution: 0 to CO₂ max.(calculation from O₂) / 0.01 vol.%
 - Accuracy: ±0.2 vol.%
- CO MEASUREMENT (325-1 only)
 - Measurement Range/Resolution: 0 to 2000 ppm / 1 ppm
 - Accuracy: ±20 ppm (to 400 ppm)

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Useful Features

- ❑ Alarms for abnormally high carbon monoxide levels – to protect both the equipment and user.
- ❑ For industrial and high temperature applications, optional high temperature sensors may be required.
- ❑ Multiple gas analysis capability including, in addition to CO₂ or O₂ and CO, NO_x, SO_x, and combustibles.
- ❑ User entered fuel composition data for off standard fuels.
- ❑ An integrated printer for printing of individual sample results.
- ❑ Optional, longer probes for use on larger pieces of equipment.

Tips for Effective Use

Take multiple measurements under a range of different firing rates – the efficiency of combustion equipment is a function of firing rate, and the calibration of fuel/air controls may change over the range of firing rates at which the combustion equipment operates.

Ensure steady state conditions for measurements – allow combustion equipment to reach normal operating temperature before taking readings.

Calibration - Typically, gas analysis equipment is not as stable as many types of temperature and pressure measurements. This means that the equipment should be calibrated frequently. The frequency will depend upon the importance of the readings to successful operation and the tendency of the calibration to drift. This could mean that the calibration check should be conducted weekly or, with experience, it might be determined that it could be extended to a monthly basis before the calibration drifted significantly. Gas analysis instruments are calibrated with bottled test gases having a certified composition similar to that of measured gases. A frequently calibrated analyzer with good repeatability should provide good performance.

4.2.8 Light Meters

4.2.8.1 Light Measurement

The light meter is designed to measure lux, the number of lumens/m² arriving at a surface. If the meter is used to measure the light leaving or reflected from a surface then it reads luminous exitance in lm/m².

Field measurements apply only to the conditions that exist during the survey. It is important to record all factors that might affect the results such as interior surface reflectances, lamp type and age, voltage and the measuring instrument.

In measuring illuminance, the cell type meter should be colour and cosine corrected. Prior to recording readings the meter should be exposed to the approximate level of illuminance to be measured for about 10 minutes. HID and fluorescent systems should be lighted for at least one hour beforehand and have had over 100 hours operation. Incandescent lights require only about a fifth of these times. Readings should be recorded in each square meter of the area and the readings averaged.



Figure 4.7: A Basic Light Meter

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The light sensitive cell should be in a horizontal plane at the workplane level or 760mm above the floor. No shadows must fall across the light cell.

To determine the reflectance factor of a surface, the incident light delivered to the surface should be measured by holding the meter cell face up on the surface. To measure the reflected light the meter cell should be placed against the surface and then drawn back about 6 to 8 cm until no shadow falls on the wall. The latter reading divided by the former equals the reflectance factor of the surface.

Table 4.1 provides some recommended levels for ready reference.

Table 4.1
RECOMMENDED ILLUMINANCE LEVELS,
POWER DENSITIES AND SURFACE REFLECTANCES

Area and Task	Illuminance	Power Density W/m ²	Reflectances %		
			Ceiling	Walls	Floor
Offices - accounting - drafting - general	750 - 950 750 - 950 540 - 700	25 25 18	70 - 80	40 - 60	20 - 40
Corridors	210	5.5			
Lobbies	320	9			
Cafeterias and Kitchens	320 - 500	14	70 - 80	40 - 80	20 - 40
Lecture Rooms	540 - 700	18	70 - 80	40 - 60	20 - 40
Toilet Areas	320	9			
Laboratories	750 - 950	25	70 - 80	40 - 80	20 - 40
Production - general	750 - 950	25			
Warehouses	320	9			
Roadways	50	2			
Parking	50	2			

Light or illuminance meters provide a simple and effective method for determining actual delivered light levels. It is useful to compare actual levels with suggested or recommended levels for specific activities or areas.

An illuminance meter typically utilizes a sensor corrected for:

- Light Colour – light sources vary in colour;
- Angle of Incidence – the cosine law is used to correct for reduced apparent illumination at small angles to the horizontal.

A basic meter is shown in Figure 4.7. This light meter is battery powered, can measure from 0 to 50,00 LUX and has a separate light sensor with a flexible cord.

Sample Specifications

- Measures 0-50,000 Lux in three ranges (0-2,000 / 0-20,000 / 0-50,000)
- Accuracy to 5%
- Automatic zero adjustment
- Sensor housed in a separate unit from display with flexible cord connection.
- Battery Operated
- LCD Display

Useful Features

- Analog output function for recording

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Tips for Effective Use

Ensure measurements are taken under steady state conditions – many lamps require a warm up period before reaching full light output.

Ensure that daylight does not influence readings – take readings at night, use blinds, or take two readings with and without lights and subtract daylight contribution to yield artificial illumination levels.

Assess wall reflectance – by taking the ratio of the reflected light to the incident light upon the wall with a light meter. Take incident light reading about 0.5 meters from wall, turn sensor to face wall and take reflected light reading.

Ensure that the light colour range of the sensor being used is appropriate for the light source present – if not apply correction factors as per light meter manual instructions.

Ensure comparable readings – lamp light output decreases with age, avoid comparing old lamps with new ones.

4.2.9 Temperature Measurement

Temperature measurements provide the auditor with opportunities to quantify thermal energy consumption and losses in a variety of ways. Air, gas, fluid and surface temperatures are commonly measured in any audit.

Types of Instruments

Temperature may be measured by a variety of contact measurements by mechanical or electrical means, and non-contact or radiation based measurements.

Bimetallic Thermometers – are constructed from two thin strips of metal with dissimilar coefficients of expansion bonded together in a coil. The coil is attached to a hand or pointer on a scale which rotates as the metals expand or contract with varying temperature.

Thermocouples – are based upon the principle that a voltage proportional to the temperature is produced at the junction of two dissimilar metals. Widely used since with wires the sensor can be used for remote reading or recording.

Resistance Temperature Detectors (RTDs) – are based on the characteristic of certain metals in which the resistance increases as the temperature increases. These devices require an external current source for the sensor to create a voltage that can be sensed and related to temperature.

Pyrometers (non-contact thermometers) – operate on the principle that objects radiate different amounts of energy according to their temperatures. These instruments measure radiation without making contact with the object and operate under an assumption of the objects emissivity (ability to radiate energy), which may be fixed or set by the user.

The following chart summarizes the temperature measurement options available to the energy auditor.

Table 4.2: Temperature Measurement Instruments

Type	Pros	Cons	Typical Ranges	Accuracy % of Span
Glass Stem Thermometer	Low Cost.	Fragile Hard to Read.	-50°C to +800°C	1% to 2%
Bimetallic	Low Cost.	Limited range. Not a remote sensor.	-60°C to +425°C	1% to 4%
Thermocouple Type T Type J Type K Type R & S	Simple Rugged Wide variety . Wide temp. range. Self powered.	Non-linear. Reference required. Least stable. Least sensitive.	-150°C to +260°C -160°C to +800°C -150°C to +1500°C -15°C to +1700°C	0.3% to 1%
RTD Nickel Platinum	Most stable. Most accurate.	Expensive. Current source required.	-150°C to +260°C -255°C to +650°C	0.1%
Pyrometers (non-contact) Optical Infrared Radiation	Safe Easy to use. Convenient.	Relatively expensive. Accuracy may be compromised by other sources in field of view.	+760°C to +3500°C 0°C to +3300°C +500°C to +3900°C	1% to 2% 1% to 2% 0.5% to 1%

Figure 4.8 shows a typical thermocouple based temperature measurement device. This consists of a thermocouple probe, in this case housed in a rugged stainless steel sheath and a digital display unit to convert the junction's output voltage to a temperature reading.

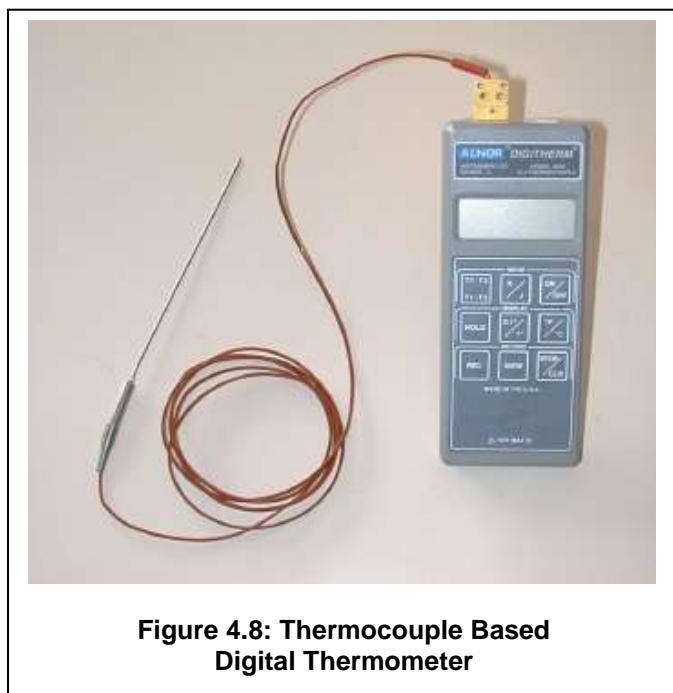


Figure 4.9 shows two versions of pyrometer or non-contact temperature measurements. The unit on the left is for close proximity readings (0.05 to 0.5m), while the one on the right is laser sighted and may be used over greater distances, dependent upon the field of view required.



Figure 4.9: Infrared Temperature Measuring Devices (Right Hand Photo: OMEGA)

Selecting an Instrument for Energy Auditing

For most energy auditing purposes thermocouples provide adequate range and accuracy. There is a wide range of sensors incorporating thermocouples for virtually any application. The sensor shown in Figure 4.8 is an immersion probe appropriate for air and water applications. Most suppliers provide a wide range of probes for many applications and temperatures.

Digital thermometer display units, similar to that shown in Figure 4.9 can accommodate a range of thermocouple styles and types, making them a versatile auditing tool.

Sample Specifications

For thermocouple based digital thermometers

- Accuracy of 0.1% reading + 0.5°C
- Input ranges: (Type K: -200°C to 1300°C)
- Resolution 0.1°C
- Ambient 0 to 50°C, 0 to 90% RH
- Reading Rate 1 per second
- Battery powered
- 6 digit LCD display

For infrared (non-contact) thermometers

- Circle or Dot Laser Sighting
- Range: -20 to 420°C (0 to 788°F)
- Resolution: 1°C/1°F
- Emissivity: 0.95 Fixed
- Spectral Response: 6-14 mm
- Optical Field of View , D:S = 8:1
- Response Time: 500 ms
- Accuracy: -20 °C to 100°C: 2°C; 101°C to 420°C: ±3%
- Operating Ambient: 0 to 50°C Less Than 80% RH

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Useful Features

For thermocouple based digital thermometer

- ❑ Analog output to allow recording measurements using a general purpose data logger.
- ❑ Max/Min capture functions – unit will display maximum and minimum temperature sensed. (the unit shown in Figure 4.8 has this function)
- ❑ Two thermocouple inputs with a differential function to display difference between the two thermocouple readings (the unit shown in Figure 4.8 has this function)

For infrared (non-contact) thermometer

- ❑ Variable emissivity for materials where emissivity not close to 0.95
- ❑ Laser sighting with a narrow field of view

Tips for Effective Use

- **Surface temperature measurements should be shielded from external influences** - Insulating material should be used to shield a contact temperature measurement sensor from contact with the air. As an example, when using a thermocouple sensor to measure pipe surface temperature, hold the sensor against the pipe with a piece of insulating foam (providing surface will not melt the material).
- **Shield sensor from sources of thermal radiation** - Often ambient radiation sources such as a hot radiator, coil or the sun will influence temperature readings if the sensor is not shielded from the radiation. This also applies to air or gas temperature sensors located near hot surfaces or in the sun. Specifically, a flue gas temperature sensor may be influenced by radiation from hot surfaces within the combustion equipment if readings are taken too close to the combustion zones.
- **Take multiple readings over a representative area** – in order to reduce error in readings due to local hot or spots on a surface.
- **Ensure sensor is not influenced by leakage into a duct or air stream** – when taking air flow readings in ducts under negative pressures, the access hole may introduce air into the duct that will influence readings. This also applies to sensing temperatures in combustion flues or vents which may be under negative pressure.

4.2.10 Humidity Measurement

Humidity measurements often used in the energy audit to assess the cooling load present in a system or to determine the amount of latent energy present in an exhaust air flow.

Types of Instruments

The psychrometer, or wet and dry bulb thermometer, is the most common instrument used and contains two temperature sensors, one with a cotton sock soaked with distilled water. The sensor with the sock will register a temperature close to the thermodynamic wet bulb temperature. Knowing the dry bulb temperature, wet bulb temperature and the barometric pressure, the relative humidity can be determined from psychrometric tables or software. Figure 4.10 shows the so-called sling psychrometer, named for the manner of use. The thermometers are rotated like a sling in the air to obtain a representative reading.



Figure 4.10 The Sling Psychrometer and Digital Humidity/Temperature Meter (Right Hand Photograph: ITM Instruments)

Electronic or digital psychrometers, similar to that pictured in Figure 4.10, are available that offer in addition to the basic wet and dry bulb readings, computations and direct reading of humidity, and data recording capability.

In addition to dedicated humidity measuring instruments, a number of the general purpose data loggers described in Section 4.2.14, include RH measurement functions.

For basic energy auditing activities the sling psychrometer offers reliable and low cost measurement - unless you have a requirement for data logging/recording of humidity measures.

Tips for Effective Use

- **Calibration of digital meters is important.** The various types of sensors used are susceptible to contamination or damage. Recalibration or sensor replacement may be required. When selecting a unit, ensure that the sensing element is suitable for the environment in which it will be used. Some sensors are particularly sensitive to high humidity, oil vapours and other organic compounds that may be present in the air.
- **Psychrometers cannot be used when the air temperature is below 0°C.** They need frequent cleaning and replacement of the cotton sock. Properly maintained, the accuracy is about +/- 0.5°C above 20% RH.

4.2.11 Air Flow Measurement

Air flow measurements are useful when analyzing facility HVAC and exhaust systems. Accurate air flow measurements are generally difficult to make and require specialized equipment. Within the context of a macro or basic micro energy audit there are some simple air flow measurements that can be made to provide data for initial estimates of energy use and savings. For more accurate measurements it is suggested that a competent air balance contractor or technician be retained.

Types of Instruments

Three relatively low cost and simple to operate instruments are suggested for basic energy audit purposes:

- **Digital Vane-Anemometer** – a rotating vane whose speed is proportional to the air speed. The uses for this device are limited due to the size of the unit and difficulty in placing the sensor in the air stream. Typically, this could not be used for in-duct measurements.

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- **Digital Thermo-Anemometer** – sensing air speed by sensing the temperature of a hot wire being cooled in the air stream. This instrument can be used in ducts and plenums.
- **Air Meter** – a very simple manometer and pitot tube assembly for low air pressures and velocity. (Figure 4.11).
- **Pitot Tube and Manometer** - is perhaps the most versatile air flow measurement device. More sophisticated manometers than that pictured in Figure 4.11 are available. Handheld



Figure 4.11 Simple Pitot Tube and Manometer Measuring Air Flow (left side) and Manometer Measuring Pressure (right side)

s with data logging functions are available for advanced applications. More robust analog manometers for instantaneous reading are also available. The added benefit of the pitot tube and manometer is that the manometer can measure pressure – required for assessment of air power.

4.2.12 Ultrasonic Leak Detectors

When gas is forced through a small opening - a leak in a pressure or vacuum system - an ultrasonic sound is created. This sound is very directional, and this directionality is used to locate the source or leak. The ultrasonic leak detector, is sensitively tuned to this frequency of sound. Typically these units have a display to indicate the strength of a leak signal, and the adjustable sensitivity allows the leak to be pinpointed with great accuracy.

Figure 4.12 shows a typical ultrasonic leak detector with its companion the ultrasonic transmitter. In areas where leaking gases are at low pressure, or a system is yet to be filled with gases, there may be no ultrasonic sound to detect. This unit allows an area to be artificially "pressurized" with ultrasound, so that small cracks and openings can be detected. Leaks can be detected in refrigeration and air conditioning systems, heating systems, steam traps, compressors and compressed air systems. This unit is useful for checking air leaks around door and window seals and gaskets, water leaks in roofs and leaks in vacuum vessels.

Typically the detector and transmitter are available in a kit that includes earphones or headphones, and extensions for leak detection in areas that are difficult to access.



Figure 4.12: Ultrasonic Leak Detector and Transmitter

4.2.13 Tachometer

Tachometers are useful to the energy auditor when the speed of a motor or driven device must be determined. Fan, pump and compressor speed are useful when comparing actual performance with nameplate or specification performance. For fans and pumps, flow is directly proportional to pump or fan speed. Motor speeds, when compared with the nameplate rated speed of the motor can be an indication of the load on a motor.



Figure 4.13 Typical Tachometer

A practical tachometer for energy auditing is shown in Figure 4.13. This unit is capable of contact or non-contact measurements:

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Contact Measurements – require the unit to be held against the end of a rotating shaft or against a belt on a conveyor to determine rotational or linear speed.

Non-Contact Measurements – relies on a light beam to be reflected off the rotating shaft. Typically, a patch of reflective tape is applied to the shaft when the device is locked off. This provides an easy target of high reflectivity.

The unit in Figure 4.13 is battery powered and has a memory function. This allows a reading to be taken, say in a position near the end of a shaft where the display is not visible, and subsequent to the measurement, viewed with the memory button.

4.2.14 Compact Data Loggers

Compact data loggers offer the energy auditor the ability to quickly and easily collect data from a wide variety of sensors and other instruments. These devices range from self contained temperature and humidity loggers to general purpose multi-channel loggers with standard analog and digital inputs.

Description

A data logger is an electronic instrument that records measurements of temperature, relative humidity, light intensity, on/off and open/closed state changes, voltage and events over extended periods of time. Typically, data loggers are small, stand-alone, battery-powered devices that are equipped with a microprocessor, memory for data storage and sensor or group of sensors. Sensors may be internal or external to the logger.

Data loggers have some form of interface to a PC and come with software to permit configuration and retrieval of data collected. Configuration allows the user to set operating parameters of the logger including:

- External sensor types connected
- Sampling intervals
- Survey start and stop times (if not immediate)
- Real time clock

Typically, the memory installed in these loggers is sufficient to allow the collection of 10,000 or more records of data, which, depending upon the measurement interval selected, could span many hours or days. Measurement intervals may be as frequent as one second or as long as one hour or more. Once a data survey is completed, the data must be downloaded from the logger for viewing or analysis with the software provided or exported to a spreadsheet for further analysis.

Applications

- Temperature and humidity and illumination level logging with internal sensors.
- Logging of other analog signals such as pressure & CO₂ sensors or any sensor with a standard current or voltage interface.
- Event logging such as motor, lights or heater on/off events.
- Logging of signals from other instruments such as light meters, digital thermometers, air flow meters and electric current clamp meters.

Useful Features

- **Data Collection/Shuttle/Transfer Capability** – this feature of some data loggers allows you to download and restart the data loggers, while in the field. The data transfer device is portable and connects to computer for the final download of data.

4.3 Historical Data Analysis - Analysing the Energy Tariff

Prior to the initial site visit, the auditor should be able to do a great deal of analysis to understand the energy purchase and usage of the facility. An important part of this historical analysis is the assessment of the energy tariff and the costs related to consumption.

4.3.1 Sources of Purchased Energy

Energy is purchased in a variety of forms, with varying energy content as shown in the table below. This information will be useful when analysing the unit cost of energy from the various sources, and later when performing savings calculations.

Table 4.3: Sources of Purchased Energy

Fuel	SI Units	
Propane	25.3 MJ/L	
Bunker C Oil	42.7 MJ/kg	40.5 MJ/L
#2 Oil	45.3 MJ/kg	38.7 MJ/L
Wood	19.9 MJ/kg	
Natural Gas	37.6 MJ/m ³	
Electricity	3.6 MJ/kWh	

An important step in conducting an energy audit is understanding how the organisation purchases electricity. In part, this relates to metering as done by the supply utility. Although there are a number of metering technologies in use which differ in various ways, the key issues for all are essentially the same, including:

- Whether or not demand is metered
- Which demand rate (kW or kVA) is measured.
- How the information is measured, stored and displayed, thermal (dials) or electronic (digital display).

A discussion of utility metering is included in Energy Basics Module 3. The following section outlines the terminology used on electric bills. A basic understanding of the structure of the bill is required to extract data for tabulation.

4.3.2 The Tariff and the Electricity Bill

Tariffs vary from location to location in South Africa. However, in general, the rates that apply to consumers are comprised of the following components:

- A fixed or administrative charge, applied per point of supply whether or not electricity is consumed;
- A demand charge, per maximum kVA registered per month;
- A consumption charge, per kWh consumed.

A sample tariff for the Ekurhuleni Metropolitan Municipality is shown below.

TARIFF C

Ekurhuleni Metropolitan Municipality - January 1, 2004

- This tariff is available for bulk supplies at any voltage and with a capacity of at least **25 kVA**.
- This tariff will suit large domestic, business and industrial customers.

The following charges will be payable:

C.1. A **fixed charge**, whether Electricity is consumed or not, per month, per point of supply:

- C.1.1. If the demand meter is switched on all the time: **R 256, 25**
- C.1.2. If the demand meter is switched off from 21:00 to 07:00 on weekdays and from 14:00 on Fridays to 07:00 on Mondays and from 21:00 on 15 December to 07:00 on 2 January: **R 512, 50**
- C.1.3. If the electricity consumption is displayed on the Internet: **R 1 025, 00**

C.2. A **demand charge**, per kVA registered, per month, per point of supply:

***Note:** If a customer connection is still equipped with a kW demand meter the customer's kVA demand will be assumed to be equal to 1,2 times the registered kW demand. The customer will however be entitled to have the kW demand meter replaced with a kVA demand meter at the customer's cost.*

- C.2.1. If the demand is registered during the meter reading periods of June, July or August: **R 53, 58**
- C.2.2. If the demand is registered during the meter reading periods of September to May: **R 47, 74**

C.3. A **consumption charge**, per kWh consumed

***Note:** If the electricity is used for domestic purposes the amount of electricity consumed shall be reduced by 50 kWh per dwelling unit per month before the above charge is calculated. If the consumption for a specific month is less than 50 kWh per dwelling unit the consumption charge will be zero.*

- C.3.1. If the kWh has been consumed during the meter reading periods of June, July or August: **16, 82 c**
- C.3.2. If the kWh has been consumed during the meter reading periods of September to May: **13, 00 c**

C.4. If the total of the demand charge plus the consumption charge above, divided by the number of kWh supplied in the month, exceeds **78, 30 c** per kWh, then the customer will be charged a rate of **78, 30 c** per kWh for energy supplied in the month.

C.5. A **rebate** according to the voltage at which the electricity is supplied

- C.5.1. If the electricity is supplied at 230/400 V: **0 %**
- C.5.2. If the electricity is supplied at a voltage higher than 230/400 V but not exceeding 11 kV: **3 %**
- C.5.3. If the electricity is supplied at a voltage higher than 11 kV: **5 %**

C.6 A **rebate** according to the following criteria

- C.6.1. If the registered demand is 5 000 kVA or higher and the load factor for the month is 90% or higher **2%**
- C.6.2. If the registered demand is 5 000 kVA or higher and the load factor for the month is 80% or higher but less than 90% **1%**
-

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The electricity bill for each utility is unique, but the information provided on the bill, in most cases, will include the following items:

- **Consumption Charge - Kilowatt Hours Used (kWh):** This is the energy consumed since the previous meter reading.
- **Demand Charge, (kVA and/or kW):** This is the actual metered value of maximum demand recorded during the billing period. If both kW and KVA are provided, the power factor at the time of the maximum demand can be calculated, and may also be provided.
- **Billing Demand (kW and/or kVA),** This is the demand value used to calculate the bill and is the Metered Demand or some value calculated from the metered demand, depending on the utility rates.
- **Tariff identifier,** defines which billing rate is applied to the energy and demand readings.
- **Days:** Number of days covered by the current bill. This is important to note because the time between readings can vary anywhere within ± 5 days, making some monthly billed costs artificially higher or lower than others.
- **Reading Date:** The “days used” and “reading date” can be used to correlate consumption or demand increases to weather dependent or occupancy factors.
- **Load Factor:** The percent of energy consumed relative to the maximum energy that could have been consumed if the maximum demand had been constantly maintained throughout the billing period.
- **Power Factor:** The ratio of recorded maximum kW to kVA. This is usually expressed as either a decimal or a percent.

4.3.3 Tabulating Energy Purchase Data

Energy consumption data is available from the organisation’s accounting records. Utility and fuel supplier invoices contain valuable information about consumption that may be tabulated.

Figure 4.14 is an example of electricity cost tabulation in an Excel spreadsheet. This sheet contains consumption data collected from bill or invoices and derived numbers that form part of the analysis. Also illustrated is an informative graphical presentation of the key data and derive values.

Starting with the basic historical billing data, a number of calculations may be performed on the data. Some of the major calculations are:

kWh/Day: kWh in period \div Days. Since reading periods can vary, kWh/day is more useful for spotting consumption trends than billed kWh.

Load Factor: kWh \div (kW x Days x 24 Hrs./Day). If metered in kVA and power factor (P.F.) is known, substitute kVA x P.F. for kW. If P.F. is not known, assume an appropriate factor (the tariff given above states that if demand is metered in kW, kVA is assumed to be 1,2 times kW—that is PF is assumed to be $1/1,2 = 83\%$). Load factor is an indication of the percentage of time the plant is operating on peak.

Electrical Load Factor (LF) is the energy consumed relative to the maximum energy that could have been consumed if the maximum (kW) demand had been maintained throughout the billing period. All the information required for this calculation can usually be found on the electricity bills. Mathematically, this is written as follows:

$$\text{Load Factor (\%)} = \frac{\text{kWh used in period}}{\text{Peak kW} \times 24 \text{ hr per day} \times \# \text{ days in period}} \times 100$$

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A high, short duration peak demand will lower the Load Factor, whereas a more consistent rate of energy consumption will raise the Load Factor.

Assume that two sample facilities consume 25 000 kilowatt-hours over a billing period of 28 days. Facility A has a maximum demand of 250 kW, while Facility B has a maximum demand of 50 kW. Based on the tariff given above, for the September to May period, their billings for this period are as follows:

Facility A:

Fixed Charge		R 256,25
Demand Charge	250 kW x 1,2 x R 47,74 =	R 14 322,00
Consumption	25 000 kWh x 13,00 c =	R 3 250,00
Total		R 17 828,25

Facility B:

Fixed Charge		R 256,25
Demand Charge	50 kW x 1,2 x R 47,74 =	R 2 864,40
Consumption	25 000 kWh x 13,00 c =	R 3 250,00
Total		R 6 370,65

Their respective Load Factors can be calculated as follows:

Facility A

$$\text{Load Factor (\%)} = \frac{25000 \text{ kWh}}{250 \text{ kW} \times 24 \text{ hr per day} \times 28 \text{ days in period}} \times 100 = 15\%$$

Facility B

$$\text{Load Factor (\%)} = \frac{25000 \text{ kWh}}{50 \text{ kW} \times 24 \text{ hr per day} \times 28 \text{ days in period}} \times 100 = 75\%$$

Facility A has a Load Factor of 15 percent and an average energy cost of 71,3c per kWh. Facility B has a Load Factor of 75 percent and an average energy cost of 25,5c per kWh. Thus Load Factor is inversely proportional to the average cost per kWh for similar facilities on the same rate.

Load Factor can be used as a barometer for a facility's use of electricity, by alerting us to excessive demand for the energy consumed. The following section provides more detail on how Load Factor can be analysed with other facility operating characteristics.

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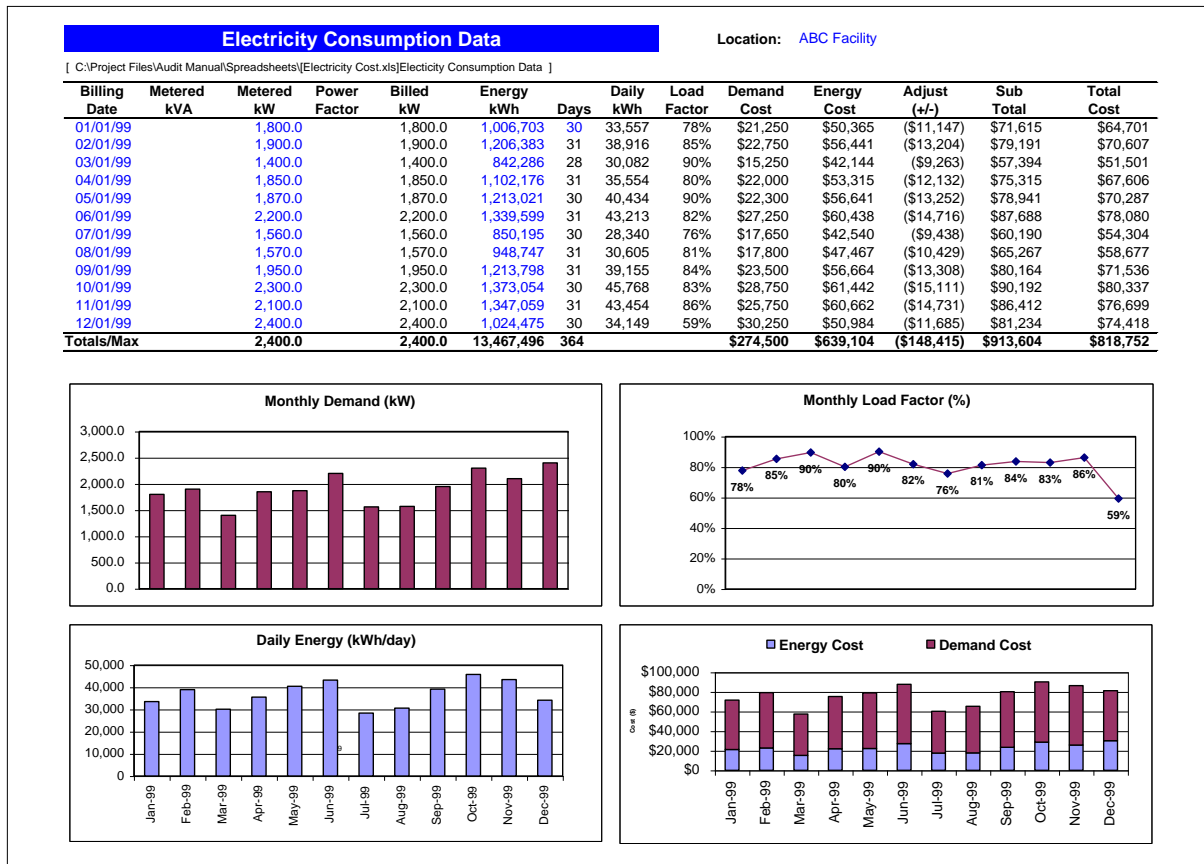


Figure 4.14: Sample Electricity Consumption Data Spreadsheet

4.3.4 Load Factor and Utilisation Factor

The utilisation factor (UF) is the percent of use (occupancy, production, etc.) of a facility. For comparative purposes, this should be calculated over the same period of time as the electrical load factor (24 hours, one week, one month, etc.). Completing this exercise is an initial step for determining the present use of electricity and a good place to start your search for savings opportunities. If there is a significant difference between the UF and the LF, further investigation is probably warranted.

Example. The UF/LF calculations can be done without any demand profile metering. All that is required is one or more electric bills and knowledge of the operation of the facility's operation.

For example, a typical school is occupied for 11 hours per day, five days a week. The UF on a weekly basis would be 55 hrs/168 hrs or 33 percent. Assume that the LF calculations yield a LF of 45 percent. The fact that the LF is roughly 1/3 higher than the UF would be cause for further investigation and more questions; are systems operating when not required? Is the school being used longer than first thought? Can system controls be adjusted or retrofitted to trim the usage closer to the occupancy hours?

4.3.5 Graphical Analysis of Historical Energy Use Patterns

Tabulation of historical bills also facilitates a graphical analysis of consumption patterns of all purchased energy forms. Figure 4.15 illustrates the patterns of gas and electricity use exhibited by four different buildings. The overall pattern of usage should to some extent be driven by the type of equipment, systems and process in a facility.

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Look for these patterns in your data. Often these patterns are as expected, and this simply confirms that there are a number of drivers of energy use in a facility. This relationship is explored further in the next chapter. Sometimes the patterns found are unexpected and can provide leads to where opportunities to modify usage and hence effect savings might exist.



Figure 4.15: Historical Energy Use Patterns for Four Different Facilities

For more information regarding gas, electricity, and fuel prices and rates contact your local utilities or suppliers.

4.4 Comparative Analysis

Based on the historical data analysis, the auditor is able to compare facility energy performance to other similar buildings as well as the subject building itself over the period for which data exist. Energy performance indices, if used carefully, are useful devices for the comparative analysis. However, in using them it is necessary to take into account differences in weather that affect building performance from region to region.

4.4.1 Energy Density Calculations

For buildings, energy density is expressed typically in MJ per square meter of conditioned floor area per year, MJ/m²/year. Calculating this factor very simply involves:

- Adding up all purchased and self-generated energy sources on a per year basis, converted to the common unit of Joules or mega-Joules, MJ;
- Dividing by the total conditioned floor area in m².

4.4.2 Correlating Energy Consumption to Weather

While the differences in climatic conditions from one place to another in South Africa, or from season to season, may not be as extreme as in some other parts of the world—Canada for example—there are nevertheless seasonal and regional differences that have an impact on building energy consumption. It is important that these factors be taken into account in the assessment and benchmarking of building performance. Since the outdoor temperature is not constant, the calculation of annual heat gain or loss involves aggregation of the heat flows at various outdoor temperatures. In a detailed audit of building energy consumption, a professional energy auditor might well use a computer to calculate the heat gain based on hourly temperature profile data. This manual, however, identifies approximation methods that will allow the auditor to estimate annual energy consumption manually. One such method uses “*degree-days*” and a second method uses “*temperature bins*”.

4.4.2.1 Degree-Days

The degree-day method assumes that, on a long-term average, heat loss to the outdoors offsets the internal heat gains (people, lighting, equipment) when the outdoor temperature is, say, 22°C (or some other temperature that characterises the energy performance of the building—the so-called “balance temperature”). That is, no additional cooling is required to maintain the desired indoor temperature. If the outdoor temperature is higher than 22°C, additional cooling is required.

Similarly, during the heating season, solar and internal heat gains will offset the heat loss when the outdoor temperature is 18°C (or the heating balance temperature). Assuming the indoor temperature is maintained at 21°C during the heating season, this means the heat loss from transmission, ventilation and infiltration loads due to a 3°C temperature difference (18 - 21) is exactly equal to the heat gain from solar and internal loads. There would be no requirement for heating energy when the outdoor temperature is 18°C.

The degree-day method also assumes that the requirement for heating or cooling energy to the building is proportional to the temperature difference between the outdoor temperature and 18°C. It is assumed, for example, that a building will require twice as much heating energy when the outdoor temperature is 10°C than when the outdoor temperature is 14°C. This is because the temperature difference at 10°C is two times the temperature difference at 14°C.

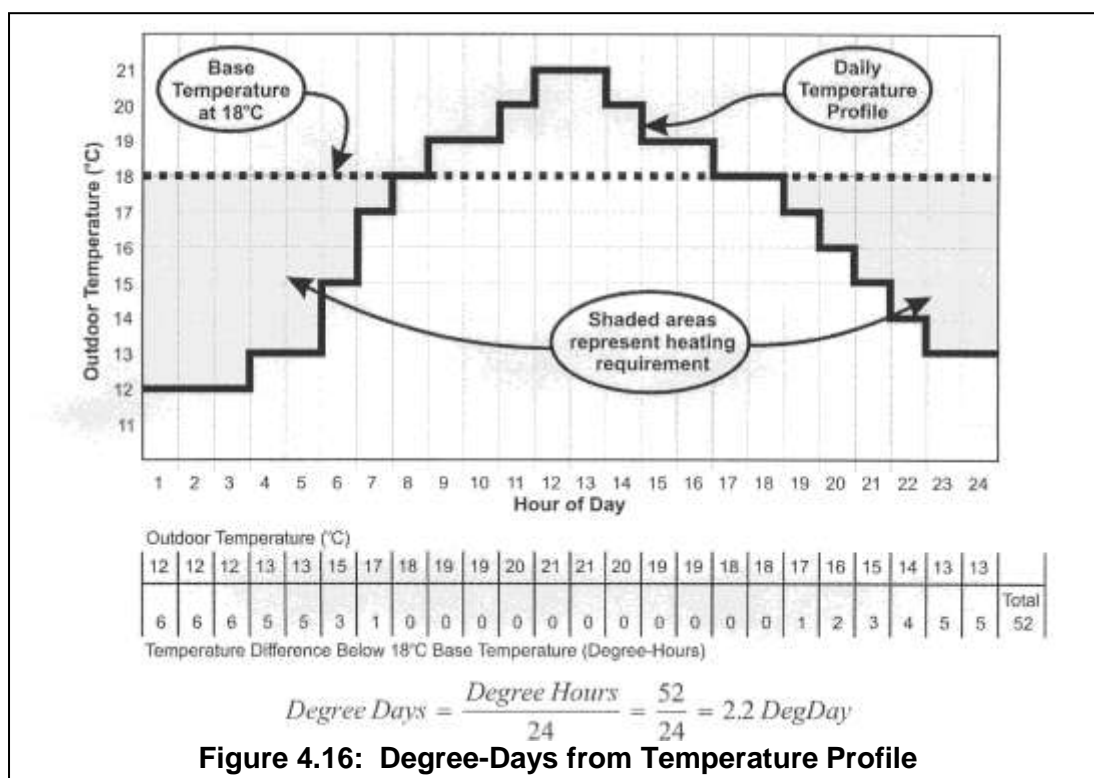
At 10°C outdoor temperature: $\Delta T = 18 - 10 = 8^{\circ}\text{C}$

At 14°C outdoor temperature: $\Delta T = 18 - 14 = 4^{\circ}\text{C}$

Degree-day data (base 18°C) is available from the meteorological stations in South Africa.

Calculating Degree-Days

Degree-days is the product of temperature difference and time, summed over a time period - usually monthly or annually. This process is illustrated in Figure 4.16, where the temperature difference at each hour is summed over the entire day to obtain a degree-hour value, which is then divided by 24 hours to obtain 2.2 degree-days. The required heating energy for this particular day is assumed to be the same as if the outdoor temperature was a constant 2.2°C below 18°C (i.e. 15.8°C) for the entire day. The temperature data can be summarized for an entire year in the same manner.



When hourly temperature data is not available, degree-days may be approximated by using the difference between the base temperature and the daily mean temperature. Applying this method to Figure 4.16, the daily mean temperature is 16.4EC, yielding 1.6 degree-days for the day (18.0 - 16.4). The difference comes because the daily mean temperature also factors in the hourly temperatures that are above the base temperature.

Applying Degree-Day Data

The rate of heat flow through the various components of a building shell is calculated from the equation:

$$Q = U \times A \times \Delta T$$

The heat flow at a given temperature difference is calculated for each building component (roof, wall, glass, etc), and then summed to obtain an overall heat flow for the building shell. Using the overall heat flow value, a composite U x A value, or overall heat transfer coefficient, can then be calculated for the entire building shell. This is illustrated in the following example.

Worked Example:

In examining a typical building, the U-values and the areas were established for the individual components of the building shell (roof, wall, glass) as shown in the table below. The heat flows were then calculated for an assumed temperature difference.

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Building Component	Q (W)	U (W/m ² °C)	A (m ²)	ΔT (°C)
Roof	56,880	3.16	1,200	15
Walls	115,710	2.90	2,660	15
Glass	12,348	5.88	140	15
Total	184,938			15

The total heat flow was then used to determine the composite UA value for the building shell as follows:

$$Q = U \times A \times \Delta T \text{ or}$$

$$U \times A = Q/\Delta T = 184,938/15 = 12,329 \text{ W/m}^2 \text{ } ^\circ\text{C}$$

To be converted to energy usage (E in Wh/yr), a time factor (t in hrs/yr) must be introduced into the heat flow equation.

$$E = U \times A \times \Delta T \times t \text{ or } E = (U \times A) \times (\Delta T \times t)$$

or

$$E = Q/\Delta T \times (\Delta T \times t)$$

The (ΔT × t) term in the above equation is in effect degree-days, or more precisely, degree-hours. Thus the equation for calculating annual energy consumption using degree-days is:

$$E = \frac{Q \times DD \times 24}{\Delta T \times 1000}$$

E = annual energy usage (kWh/yr)

Q = total heat flow for building (W)

ΔT = assumed temperature difference (°C)

DD = annual degree-days heating value at base temperature

24 and 1000 are constants to convert days to hours and Wh to kWh

Referring back to the worked example, assume the building is at a location where 640 degree-days heating is reported at 18°C base temperature. The annual heating energy requirement for the building is calculated as follows.

$$E = \frac{Q \times DD \times 24}{\Delta T \times 1000} = \frac{184,938 \times 640 \times 24}{15 \times 1000} = 189,377 \text{ kWh/yr}$$

The same equation can also be applied to determine the heating or cooling energy requirement of ventilation and infiltration loads.

Using Degree-Days for Cooling

The degree-day method can also be used for estimating annual cooling energy usage. Instead of using a temperature difference below the base temperature as for heating, the cooling degree-day value is calculated using the temperature difference

Referring back to the daily temperature profile in Figure 5.29, there are 14 degree-hours above 18°C, or 0.6 degree-days cooling (14/24).

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A different base temperature is usually used for determining cooling degree-days. Assuming the indoor building temperature is allowed to rise to 25°C during the cooling season, and assuming solar and other internal heat loads provide 3°C of heating, then cooling energy is required whenever the outdoor temperature rises above 22°C. Thus cooling degree days are often calculated using a 22°C base

One disadvantage of using the degree-day method for estimating cooling energy is that, in addition to temperature difference, humidity is also a critical factor for determining cooling energy. The degree-day method does not accommodate this factor. The “temperature-bin” method outlined in Section 5.6.2.2 will provide more accurate cooling energy estimates.

Modified Base Temperature

The standard convention of 18°C base temperature for heating assumes that the building space temperature is allowed to fall to 21°C during the heating season, and that the solar load together with the normal composition of people, lighting, and equipment provide sufficient heat gain to offset the heat loss from 3°C temperature difference. Thus 18°C is considered the “balance temperature” at which the heat losses equal the heat gains and there is no net requirement for heating or cooling energy.

In some buildings the characteristics of the building systems and occupants may be such that the heat losses and gains balance at an outdoor temperature different than 18°C. The following procedure can be used to determine a new balance temperature.

The overall heating requirement for the building is the sum of heat losses and heat gains. The various heat losses and gains can be categorized as weather-related (transmission, ventilation and infiltration) and non-weather-related (people, lights, equipment), where the weather-related factors depend upon the difference between indoor and outdoor temperatures. This relationship can be shown as:

$$Q = UA \times (T_{out} - T_{in}) + (P + L + E)$$

where:

- Q = overall heating requirement (W)
- UA = composite value incorporating transmission, ventilation and infiltration components (W°C)
- T_{IN} = indoor temperature (°C)
- T_{OUT} = outdoor temperature (°C)
- P = heat gain from people load (W)
- L = heat gain from lighting load (W)
- E = heat gain from equipment load (W)

(Note sign convention assumes heat supplied to the building envelope is positive and heat removed from the building envelope is negative.)

The balance temperature (T_B) is the outdoor temperature at which the overall heating requirement for the building is zero.

$$Q = UA \times (T_B - T_{in}) + (P + L + E)$$

or

$$T_B = T_{in} - (P + L + E)/UA$$

Worked Example

Referring back to the previous example, it was discovered that the ventilation system delivers 1,200 L/s and operates 24 hours/day, 365 days/year. Two measures are being considered - one is to reduce the ventilation air flow from 1,200 L/s to 800 L/s, and the second is to cut back the continuous operation to 8 hours/day, 5 days/week. Estimate the combined heating energy reduction that can be achieved from these measures.

As we saw in Module 2, the heat flow for 1,200 L/s air at 15°C temperature difference (assumed) is:

$$Q = 1.232 \times F_A \times \Delta T = 1,232 \times 1,200 \times 15 = 22,176 \text{ W}$$

The annual heating energy requirement for this ventilation air, with 640 degree-days heating

$$\text{New } E = 22,708 \times \frac{800}{1200} \times \frac{8}{24} \times \frac{5}{7} = 3,604 \text{ kWh}$$

is:

The new energy requirement after reducing the flow from 1,200 L/s to 800 L/s, and reducing the operation to 8 hours/day and 5 days/week is:

$$E = \frac{Q \times DD \times 24}{\Delta T \times 1000} = \frac{22,176 \times 640 \times 24}{15 \times 1000} = 22,708 \text{ kWh}$$

The reduction in heating energy requirement from these measures is:

$$22,708 - 3,604 = 19,104 \text{ kWh/yr.}$$

4.4.2.2. Temperature Bin Method

Another technique for approximating annual energy usage is the temperature bin method. With the temperature bin method, the hourly temperature data for the year are sorted into groups, or bins, each bin representing a small temperature range of say, 3°C.

The building's heating/cooling performance is calculated for the outdoor temperature represented in each temperature bin, using the midpoint temperature, e.g. 19.5°C for the 18°C to 21°C range. The energy usage for each bin is calculated by multiplying the energy flow by the number of annual hours for that bin.

The calculations required for the temperature bin method are longer than for the degree-day method. However, the temperature bin method can provide a more accurate assessment. There are two reasons for this:

- a) The temperature bin method allows the auditor to consider the building's hourly energy requirements for a particular bin and system efficiencies can be factored in accordingly. For example, the air conditioning system would operate at a much lower efficiency during low-load conditions than if it was operating near its rated capacity. The same applies to heating systems with a fuel fired heat source.

The degree-day method does not allow this judgment. If a location has a given degree-day value of 1,000 DD for cooling, the auditor has no understanding of the temperature profile. The building could experience a 20°C temperature difference for 50 days, or a 4°C temperature difference for 250 days during the year. There would be a significant

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difference in the operating performance and system efficiencies under these two scenarios, but there is no information to assess the situation.

- b) The second advantage, which applies mainly to cooling requirements, is that the auditor can apply a typical wet bulb temperature to each temperature bin, and factor the effect of latent heat into the calculations. This is especially beneficial in assessing air conditioning systems.

4.4.2.3 Regression Analysis of Energy Consumption

As a basis for our analysis we must establish a simple but physical relationship between energy use and weather in a building. In simple terms, the energy required to heat the building during the heating season is equal to the heat lost from the building into the surrounding environment, through building walls, windows, and vents; and the energy required to cool the building in the cooling season is equal to the heat gained from the surrounding environment. In each case, the internal heat load is a factor—subtracting from the heat requirements or adding to the cooling requirements.

The rate at which heat loss or gain occurs is determined mainly by two key factors:

- the temperature difference driving force, being the difference between the indoor and outdoor temperature;
- and the thermal performance of the building.

Table 5.16 gives average temperatures for Cape Town for the period 1961 to 1990. From these data, we can calculate the number of degree days, both HDD and CDD for selected base temperatures (we are using 18°C for HDD, 20°C for CDD to illustrate.)

Similarly, the CDD is defined as the sum of the differences between the average outdoors temperature and a suitable reference, such as 20°C.

Table 4.4: Degree-Day Calculations for Cape Town

Month	Days	Tavg.	HDD18	CDD20
J	31	20.9	0.0	27.9
F	28	21.0	0.0	28.0
M	31	19.8	0.0	0.0
A	30	17.5	15.0	0.0
M	31	14.8	99.2	0.0
J	30	13.0	150.0	0.0
J	31	12.2	179.8	0.0
A	31	12.7	164.3	0.0
S	30	14.0	120.0	0.0
O	31	16.0	0.0	0.0
N	30	18.4	0.0	0.0
D	31	19.9	0.0	0.0
Yearly			728.3	55.9

So in July, we see the heating degree-days indicated as 179.8 for the recorded average daily mean temperature of 12.2°C. Note that the calculation yields negative answers in HDD when the average temperature is greater than 18, or in CDD when the average temperature is less than 20; however, negative answers are meaningless because they simply indicate that no heating was required in the first case, or no cooling was required in the second case.

Although oversimplifying a complex physical situation, we might think of the overall building having a coefficient of heat loss—let's call it U —which relates the rate of heat loss to the temperature difference driving force. The total heat lost in a period is then the integral of the

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instantaneous heat loss rate. We can then say that the heat lost is directly proportional to the driving force, or the HDD measure:

$$H \propto \text{HDD}$$

$$\text{Or } H = U \times \text{HDD}$$

with the constant of proportion being the heat transfer coefficient of the building. This provides a theoretical basis for the empirical expectation that energy plotted against HDD is a straight line.

What we have established so far is that it is reasonable to plot energy against HDD or CDD and to expect a straight line. Indeed, that is what is commonly found, with a straight line produced of the form:

$$y = mx + c$$

where **c**, the intercept, and **m**, the slope, are empirical coefficients. For our working example this is shown in Figure 4.17 in which the base year (1999/2000) heating season data are used. In fact, there are three features in Figure 4.17. Apart from **c** and **m**, another feature is the **scatter**. The graph points in Figure 4.17 represent the energy consumption on a billing period basis, plotted against the HDD for that period. As expected, the kWh energy consumed increases with HDD, although there is some scatter, in particular one or two points that fall well below the trend established by the others.

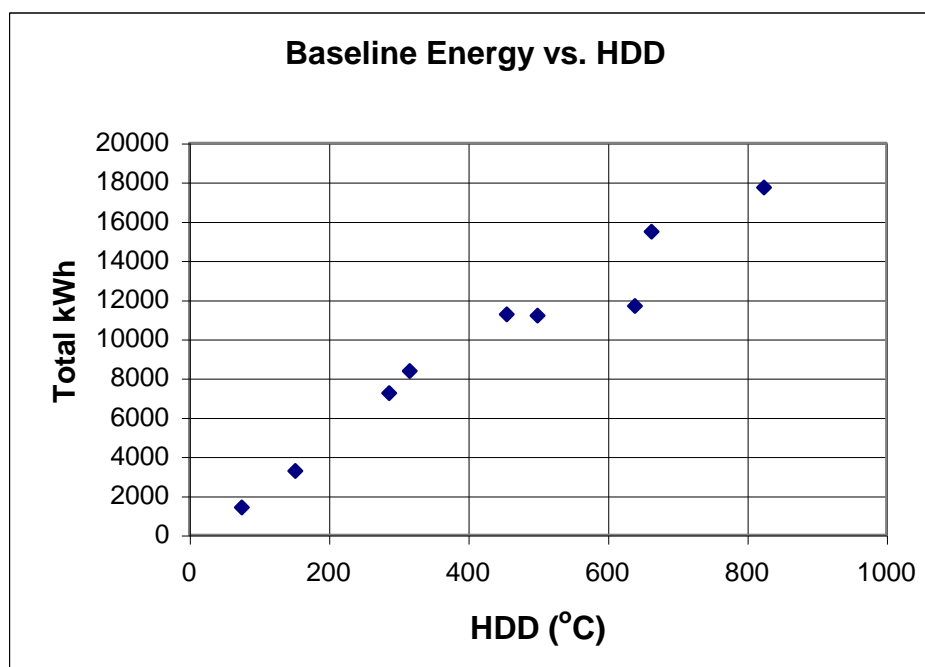


Figure 4.17: Energy Consumption vs. HDD Scatter Plot

Linear regression is the technique of finding the straight line that best represents the scattered points; this mathematical process can be done with a key-stroke in a spreadsheet program like Excel. For the example above, Figure 4.18 shows the result of the regression along with the performance equation.

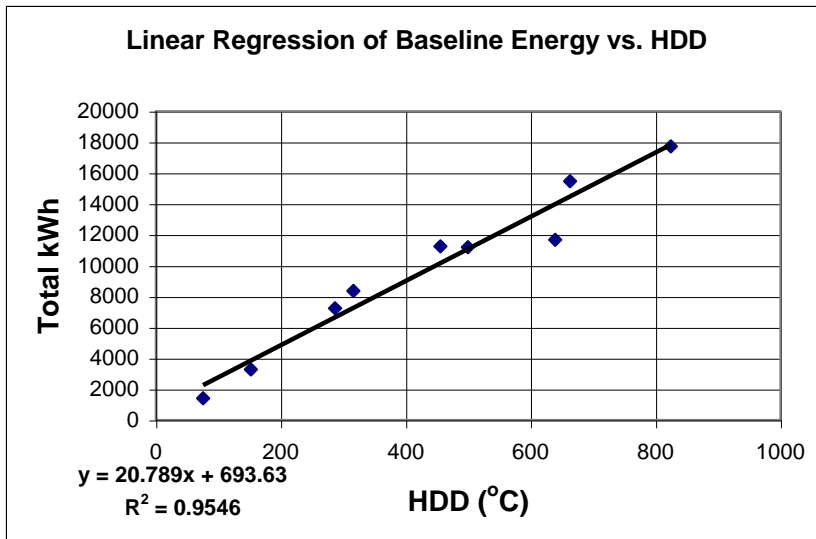


Figure 4.18: Linear Regression of Baseline Energy Use