Department of Minerals and Energy, Pretoria

Capacity Building in Energy Efficiency & Renewable Energy

Report No. 1.1 Auditing

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Department:
Minerals and Energy
REPUBLIC OF SOUTH AFRICA

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Abbreviations and Acronyms

BEE	Black Economic Empowerment
CaBEERE	Capacity Building in Energy Efficiency and Renewable Energy
CB	Capacity Building
CEF	Central Energy Fund
DANIDA	Danish International Development Assistance
DDG	Deputy Director-General
DEAT	Department of Environmental Affairs and Tourism
DK	Kingdom of Denmark
DKK	Danish Kroner
DME	Department of Minerals and Energy
DPW	Department of Public Works
DTI	Department of Trade and Industry
EE	Energy Efficiency
EMO	Energy Management Opportunity
ESCO	Energy Service Company
ESETA	Energy Sector Education Training Authority
FIDIC	Industrial Federation of Consulting Engineers
IDC	International Development Corporation of South Africa
NT	National Treasury
NER	National Energy Regulator
NGO	Non-Governmental Organisation
PDI	Previously Disadvantaged Individual
PM	Project Manager
PQ	Pre-Qualification
PSC	Project Steering Committee
PTT	Project Task Team
QA	Quality Assurance
RE	Renewable Energy
RSA	Republic of South Africa
SA	South Africa / South African
SALGA	South African Local Government Association
SANGOCO	South African Non-Governmental Organisations' Committee
SARS	South African Revenue Service
SMME	Small, Medium and Micro Enterprises
SP	Service Provider
ST	Short Term Adviser
TA	Technical Assistance
TOR	Terms of Reference
VAT	Value Added Tax
ZAR	South African Rand

1 Introduction

This document describes the complete process of conducting an Energy Audit in a building. The objective of Energy Auditing is to analyse thoroughly the energy consumption and demand of a building and determine if viable energy savings can be made.
In order to ascertain at an early stage whether the building is consuming above or below average, a Preliminary Audit is carried out. This first phase of the Auditing Process gathers a minimal amount of data and compares energy indices to benchmark figures. The comparison of these benchmark figures indicates if the building is already energy efficient, in which case no extra effort needs to be put in to determine if energy savings can be made. The Auditing process will only proceed to the second phase (Detailed Audit) if the energy efficiency is proved to be worse than average.

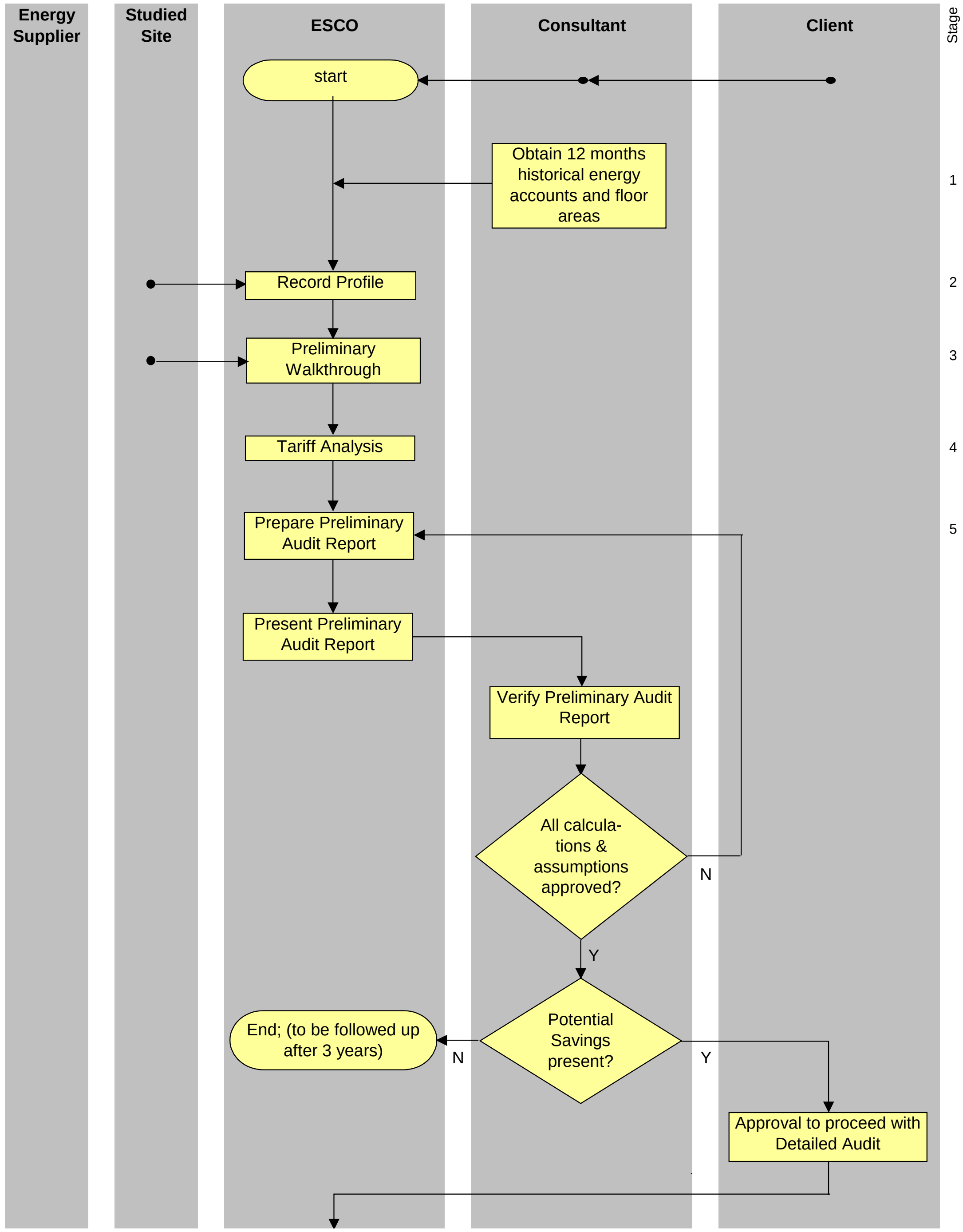
During the Detailed Audit, all facets of energy savings are checked in a systematic way. Cost of implementation and predicted savings of every proposed strategy are calculated, which gives the payback time.

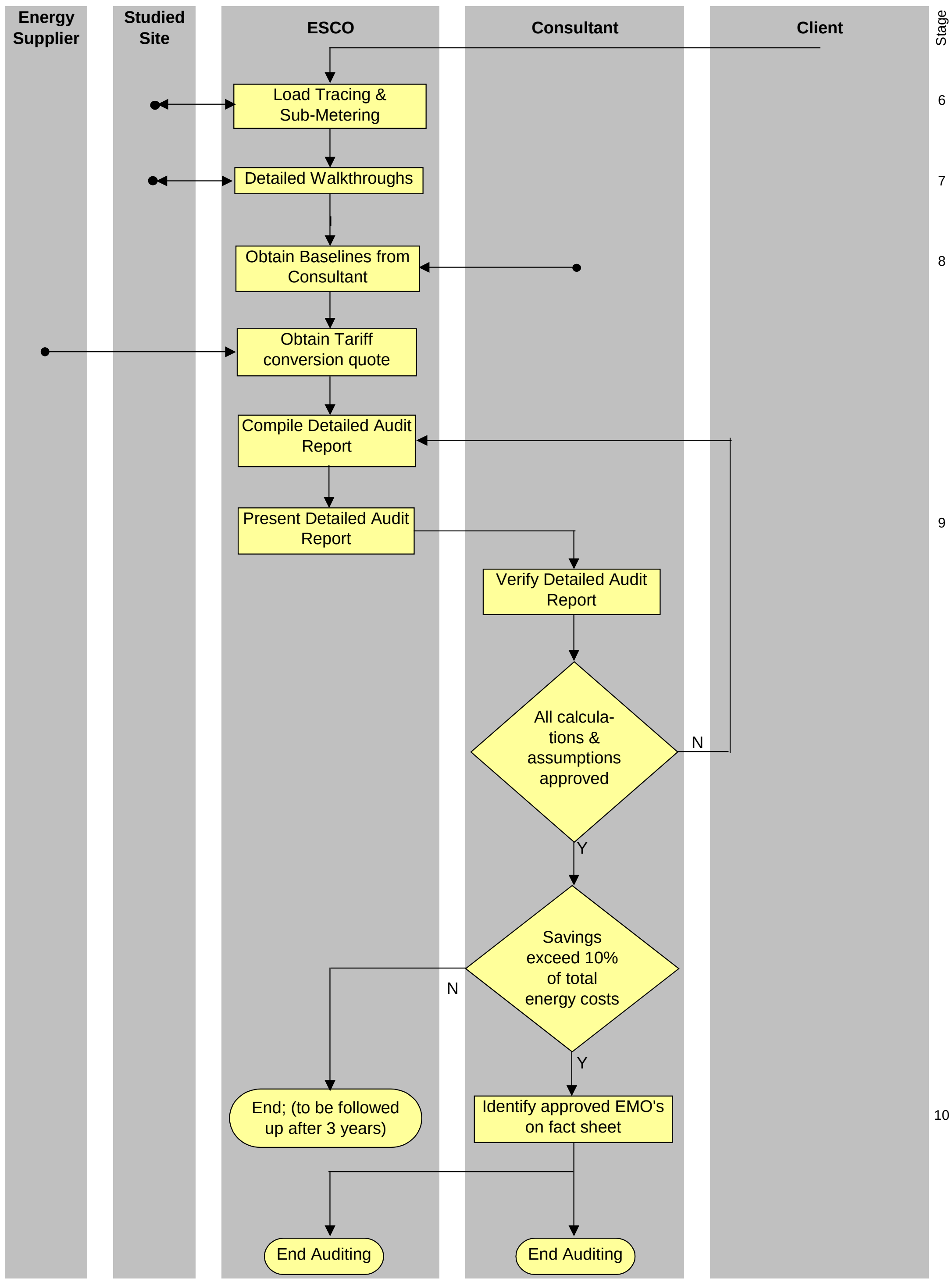
Auditing forms an integral part of the total process of energy saving. It is the first step and therefore the basis of all future works to obtain real savings. Because auditing is the foundation, calculations and assumptions need to be transparent, so checking should easily reveal errors, if any were made. It is a common responsibility of both ESCO and Consultant to make sure that everything stated in the Audits is 100% true.

Auditing is not a once-off exercise. Energy prices are increasing and new technologies are being developed, making more and more energy management opportunities viable every year. It is recommended that Auditing takes place every 3 years.

2 Flow Chart for Auditing a Building

The following Flow Chart summarises the process of conducting an Energy Audit as described in more detail in this document.




Energy Supplier
Studied Site
ESCO
Consultant
Client
Stage
6
7
8
9
10
Load Tracing & Sub-Metering
Detailed Walkthroughs
Obtain Baselines from Consultant
Obtain Tariff conversion quote
Compile Detailed Audit Report
Present Detailed Audit Report
Verify Detailed Audit Report
All calcula-tions & assumptions approved
N
Y
Savings exceed 10% of total energy costs
N
Y
End; (to be followed up after 3 years)
Identify approved EMO's on fact sheet
End Auditing
End Auditing

3 Preliminary Audit

The purpose of the Preliminary Audit is to scan a building quickly in order to give an accurate indication whether the energy consumption of the building or complex of buildings is normal or too high. If the energy consumption corresponds with benchmark figures (energy indices) for similar buildings, that are found energy efficient and the usage profile does not reflect any anomalies, it is better to focus on other buildings with more obvious inefficiencies.
The following sections identify the tasks that must be carried out during a Preliminary Audit. All tasks are grouped in stages, which need to be followed in the sequence as presented in this document. Although stages may be performed simultaneously, the order should not be altered as most stages require results from a previous stage.

3.1 Stage 1; Obtaining historical energy accounts

All energy sources that are used by the client should be identified. In South Africa the main energy source is electricity. For heating, various other energy sources are used, e.g. coal, gas, oil, paraffin, diesel, steam etc. At least one year of historical consumption is required for the Preliminary Audit.
For buildings under the control of National Government, the Department of Public Works (DPW) usually pays the electricity bills. Obtain at least 12 months of historical accounts from them. If this information is untraceable from the user department or client, it should be obtained from the electricity supplier. Note that these authorities require permission from the client in order to provide the information. Sometimes the authorities will charge a small fee for retrieving the information.
The client, as mentioned above, is the one who pays the electricity account, which is DPW in most cases.

For the other (fossil) fuel sources a record should be kept on site by the maintenance or facility department. At least one year of consumption must be retrieved, including the cost. DPW usually pays these accounts, although in some situations the occupant pays the supplier and recovers the costs at DPW.

Make sure you retrieve both quantities and costs. Energy quantities are kWh, kVA, kg of coal, kg of propane, tons of steam (also record the incoming pressure) or litres of oil, diesel, paraffin, etc.

3.2 Stage 1; Obtaining floor areas

There are various ways to obtain floor areas. The easiest is to ask the client whether these figures are available. Floor areas are used for cleaning contracts and sometimes maintenance contracts.

Another possibility is to obtain the architect’s drawings. The areas might be on those drawings; otherwise it is easy to determine them by simply measuring.
The last option is to measure the areas physically on site.

For a good comparison, the nett floor areas should be used. The definition of nett floor area is roughly: An area that is for the direct use of occupants and is occupied during all or most of the working day. For a more precise definition, see Appendix C.

3.3 Stage 2; Record electricity profile

At the electricity incomer (typically where the electricity meter is) the consumption should be logged. Some electricity meters have the feature to record the electricity profile, however, only the authority can retrieve this data and usually there are costs involved.

If the profile cannot be retrieved from the meter, install a logger that will measure kVA, kW, kVAr and the Power Factor. Metering interval should be set to the same interval as the block interval used by the supply authority. Shorter intervals than the above-mentioned are also allowable.

The required recording period is at least 2 weeks, although longer periods are preferable. Ideally the period should coincide with the metering period of the supply authority, but in practice this is difficult to achieve.

3.4 Stage 3; Preliminary Walkthrough

A brief walkthrough should be carried out, focusing on the air conditioning system, lighting system, hot water system and other major energy consumers.

On the air conditioning system, visually check the state of the system, in particular:

- Type of system.
- Any integrated energy efficiency strategies (e.g. economy cycle or night flushing).
- Condition of insulation.
- Do the plants run with timers?
- Level of maintenance.

The following lighting aspects should be checked:

- What types of lights are used?
- Are outside lights on during daytime?
- Measure light intensities in various locations, especially where it is dark or very light.
- Ask if lights are on timers or daylight switches and, if so, check the settings.

For hot water production, check the following:

- What are the hot water temperatures and the thermostat set points?
- Visually check the state of the installation, condition of insulation.
- What fuel is used?
- Where is the hot water used? Are water efficient appliances used?
- Age of the hot water producing equipment.

Examples of the most common other main energy consumers are:

- Kitchen equipment.
- Compressed air production equipment.
- Washing machines and tumble driers.
- Pumps.

3.5 Stage 4; Tariff Analysis

3.5.1 Obtain tariff structures from supply authority

Eskom is the main electricity supplier in South Africa but most clients buy their electricity from municipalities. In the future this will probably change to REDs (Regional Electricity Distributors), but in whichever scenario, it is important to obtain the tariff structures from the supplier.
Electricity tariffs can be split into 3 types:

- Consumption Tariffs; the client is charged for the consumption at a fixed R/kWh rate. Sometimes it includes a service fee for the meter.
- Demand Tariff; the client is charged for the consumption at a fixed R/kWh rate as well as for the maximum demand that occurred during that month (kVA). The consumption part is cheaper than in a Consumption tariff, but the rate for the

maximum recorded demand is high. There are always services charges involved with this tariff.

- Time-Of-Use (TOU) Tariff; the client is charged at a different consumption rate depending on the time of the day/week/season the electricity was consumed. Some tariffs only distinguish between peak (day) and off-peak (night), others have a more complex peak (during national peak), standard (day) and off-peak (night) split. The maximum demand and/or reactive energy can also be charged in this tariff; a service fee is always charged.

Not all of the above electricity tariff types are available at every electricity supplier.

For other fuel sources stacked tariffs are sometimes used. If more of the fuel source is used, a discount is given by the supplier. Obtain these tariff structures also.

3.5.2 Tariff Analysis

The aim of a tariff analysis is to investigate potential cost reductions for the client, without changing the consumption profile.
From the different tariff structures obtained from the supply authority, check if there are other tariffs applicable to the site. Some consumption tariffs have minimum or maximum allowable connection capacity (i.e. 3x60A or 3x80A).
Time-Of-Use (TOU) Tariffs usually are not applicable to Very Large Users (HV users) whereas Demand Tariffs are not applicable for Small Users.

If there are different tariffs that are applicable to the site, use the recorded data (see 3.7.2) to calculate the various tariff scenarios.
Start to calculate what the recorded profile would cost by multiplying the (various) consumption prices by the recorded kWh. Take note that kW's were recorded at certain intervals. 1 kWh is 1 kW of power used for 1 hour. 1 kW used for 5 minutes is only 1 kW x 5/60 = 1/12 kWh! If the client is on a TOU Tariff, the different consumption rates should be taken into account for the different time slots.
If the client is on a Demand Tariff, the Demand cost should only be multiplied once by the maximum recorded demand (remember that the supply authority only charges for the maximum recorded demand in a month).
This exercise should be repeated for all the appropriate tariffs.

The difference in costs indicates which tariff is the preferred one for the site. To estimate what the annual cost reduction will be, the calculation has to be corrected to the historical accounts. Note that most tariffs have seasonal differences; winter prices are higher than in the rest of the year. To interpolate, increase the calculated consumption costs pro rata to the historical consumption figures as given on the historical accounts. The same method is used for the maximum demand costs.
This method is not 100% accurate as it assumes a similar daily profile for the whole year. It is, however, too costly and time consuming to record the profile of a whole year. Also, it is an indication and not a prediction of what really will happen in the future.

Once the benefit of changing tariffs is clear, a few points have to be taken into account:

- Some supply authorities will charge a conversion fee to compensate for revenue losses.
- Changing tariffs sometimes requires a different electricity meter; this is a once off cost.

3.6 Stage 5; Finalising the Preliminary Audit

Once all of the above information is gathered, the Preliminary Audit can be finalised.

3.6.1 Generating indices

All energy inputs need to be converted to MJ. Use Table 1 to convert the various energy sources to MJ.

Energy source	Source unit	Multiply by to obtain MJ
Electricity	1 kWh	3.6 MJ
HFO	1 kg (ρ=980 kg/m^3)	42.6 MJ
LPG – Propane	1 kg (ρ=508 kg/m^3)	50.4 MJ
Paraffin	1 kg (ρ=726 kg/m^3)	46.0 MJ
Petrol (99 octane)	1 litre (ρ= 720 kg/m^3)	33.0 MJ
Diesel	1 litre (ρ= 800 kg/m^3)	37.0 MJ
Coal	1 kg (ρ varies)	30.0 MJ (varies)
Wood (50% mc)	1 kg (ρ= 738 kg/m^3)	10.2 MJ
Wood (40% mc)	1 kg (ρ= 640 kg/m^3)	12.2 MJ
Wood (30% mc)	1 kg (ρ= 541 kg/m^3)	14.2 MJ

Table 1 Energy conversion factors

The total annual energy consumption in MJ divided by the nett floor area is the **consumption index**. The unit of energy consumption index is MJ/m^2/annum

If the electricity tariff is a demand tariff (see 3.5), the demand index should also be calculated. The average monthly maximum demand divided by the nett floor area is the **demand index**. The unit of demand index is $VA_{average}$/m^2/month.

Compare the calculated index/indices with benchmark figures similar to the audited site, given in Appendix A.

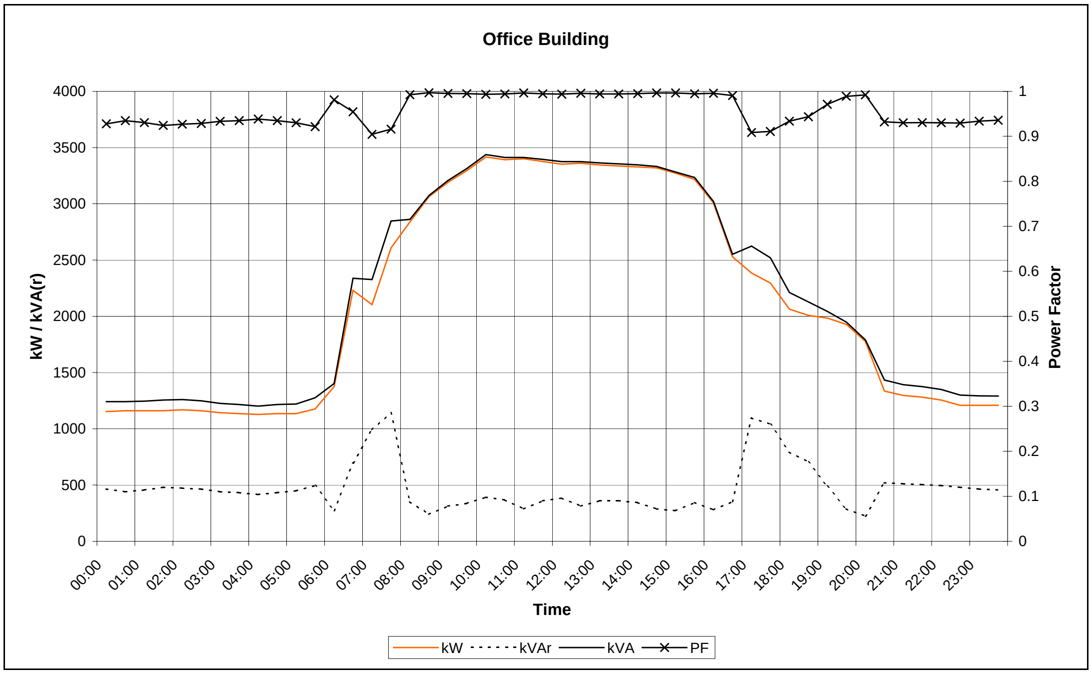
3.6.2 Analyse recorded electricity profile

Plot the kW, kVA and kVAr against time (in one graph). Produce graphs for entire logging period. Graphs should be readable; one graph should not include more than one week's information.
Generate one graph for the peak day (when maximum demand occurred).

From these graphs the following can be extracted:

- Maximum demand, highest kVA value recorded.
- Power Factor at time of maximum demand
- Nightload / Dayload ratio
- Daily load patterns (predictable or not)

Graphs 1 and 2 give two profiles that will be analysed as an example.

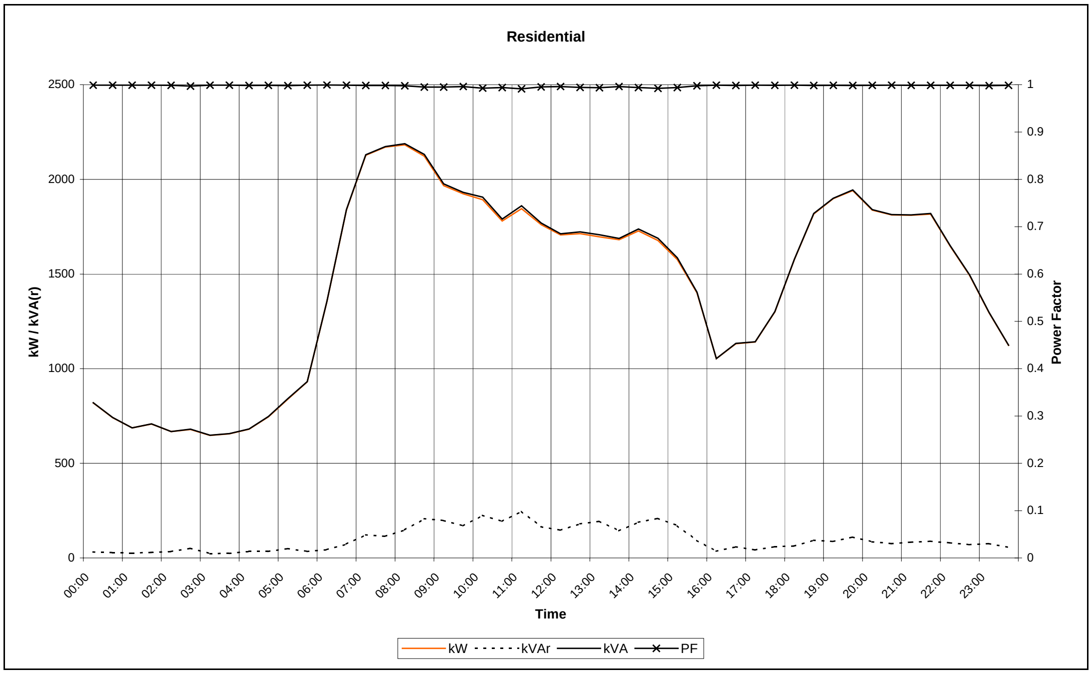


Graph 1: Example of an office building

In Graph 1 the following can be noticed:

- The maximum recorded demand occurred at 11:00 in the morning, it was approximately 3450 kVA.
- The Power Factor was 0.99 at the same time, which is good. This is because of the installed Power Factor Correction (see 4.2.2), which compensates for the bad power factor created by motors (of fans, compressors and pumps) and transformers (in appliances or magnetic ballasts for fluorescent lights).
- The night load is fairly high for offices (approximately 30% of the day load), which could indicate that lights, equipment or even air conditioning was left on. Also the gradual decrease from 17:00 until 23:00 is of concern. It could mean that large numbers of personnel are working overtime, or that the air conditioning is running after hours (and is slowly cooling down the building, until it has reached the set temperature).
- This electricity profile occurred every working day, which makes it predictable. Personnel are coming in between 7:30 and 8:30, so the load shoots up.

Also the Power Factor is getting worse during the night, which indicates that kVA is bigger than kW. This is not of great concern as the client will only be charged for the maximum recorded demand.



Graph 2: Example of a residential site

In Graph 2 the following can be noticed:

- The maximum recorded demand occurred at 8:00 in the morning; it was approximately 2200 kVA.
- The Power Factor was 1.00 at the same time, which is excellent. This is because the geysers in houses are creating the peak. Heating elements are resistive load and do not cause reactive power, and therefore do not create a bad power factor.
- The night load is average for residential sites (approximately 35% of the maximum demand) and is mainly caused by (street) lights and geysers maintaining their temperature.
- Every residential site has a similar electricity profile (high morning and evening peak) and is therefore very predictable.

The strategies for reducing electricity consumption in residential sites are limited because of the impact on individual freedom. It requires good awareness campaigns.
However, on the demand side there are some efficient strategies. For instance, a geyser does not always have to recover to its setpoint temperature after 2 hours; in some cases it can be extended to a longer period. This does not reduce the consumption (the amount of water will still need to be heated) but it significantly reduces the morning and evening peaks.
Also changing from electricity to a different fuel source can eliminate the demand peak, which could make the conversion viable.

3.6.3 Additional required information

The Preliminary Audit should also include the following:

- If a site has varying occupancy numbers, these figures will have to be obtained and included (number of pupils, inmates or beds at time of carrying out the Preliminary Audit).
- If the outcome of the Preliminary Audit indicates that energy savings can be made, a price for carrying out the Detailed Audit should be included.
- Substantiate the conclusion that potential energy savings can be made (e.g. poor Power Factor, high night load, high energy indices, etc.)

4 Detailed Audit

Once the Preliminary Audit indicates the potential for savings, and approval is given to carry out the Detailed Audit, the ESCO may proceed with this chapter.

4.1 Stage 6; Detailed Audit; Preparation work

4.1.1 Obtain site drawings

An overall site drawing is helpful to orientate oneself and it facilitates the planning of load tracing.
Electrical drawings of all substations and distribution boards should be obtained. This is not always possible, but try to get as much information as possible. This will eliminate puzzling during load tracing and walkthroughs.

4.1.2 Load Tracing

The first real step in a Detailed Audit is to have a good understanding of where electricity is consumed. Especially in bigger sites, this requires a systematic approach.

- Walk through the site and measure the amps of every group in every distribution board and every substation. Grouping should be categorised by lights, kitchen, cooling plant, hot water plant, etc. If, in the Preliminary Audit, a high night load was ascertained, this exercise should also be carried out at night.
- Compile the data in a spreadsheet, converting the amps per phase to kVA. **Identify the largest groups that make up 80% of the total load.** This will be the part of the installation that will be focused on.

4.1.3 Sub Metering

Sub meter the identified large loads for a full week. Some loggers can record more than one group, which helps speed up the sub metering process.

Once all this data is gathered, the info should be stored in spreadsheets and electricity profile graphs should be made for quick comparison of the profiles of all measured groups.

4.2 Stage 7; Detailed Walkthroughs

4.2.1 Lighting

The following aspects of lighting should be checked.

- Investigate changing lighting control; indicate how light groups are controlled and if improvements can be made. The various controls are: centralised manual switching, manual switching in groups, manual switching per room, automatic central switching, automatic timer switching per room / area, automatic day/night switching of outside lights, automatic switching through occupancy detector. Other types of switching may be considered.
- Investigate converting light types (retrofit), from inefficient lighting type (typically incandescent) to more efficient type (halogen, fluorescent, compact fluorescent, LED lighting, etc.). Make sure that, in the case of compact fluorescent lights, a separate (and not integrated) control gear is installed. Experience teaches that lights with integrated control gear are often stolen.
- Investigate lighting levels; these should conform with the Occupational Health and Safety Act and relevant SABS standards. If lighting levels are too high, investigate de-lamping.

- Investigate the possibility of day lighting. Sunshine is for free, but will also allow heat to enter the building. Make sure the energy savings calculation includes both lighting savings and increase in air-conditioning load.
- Investigate changing magnetic ballasts on fluorescent lights to electronic control gear.
- If electronic control gear on fluorescent lighting is already in place, investigate daylight dimming for areas that have plenty of natural daylight entering the building. This could be incorporated with occupancy sensors (these combi sensors are available)

For all energy saving calculations on lights with control gear (gas discharge lamps) the consumption of the control gear has to be included in the calculation.

4.2.2 Power Factor Correction

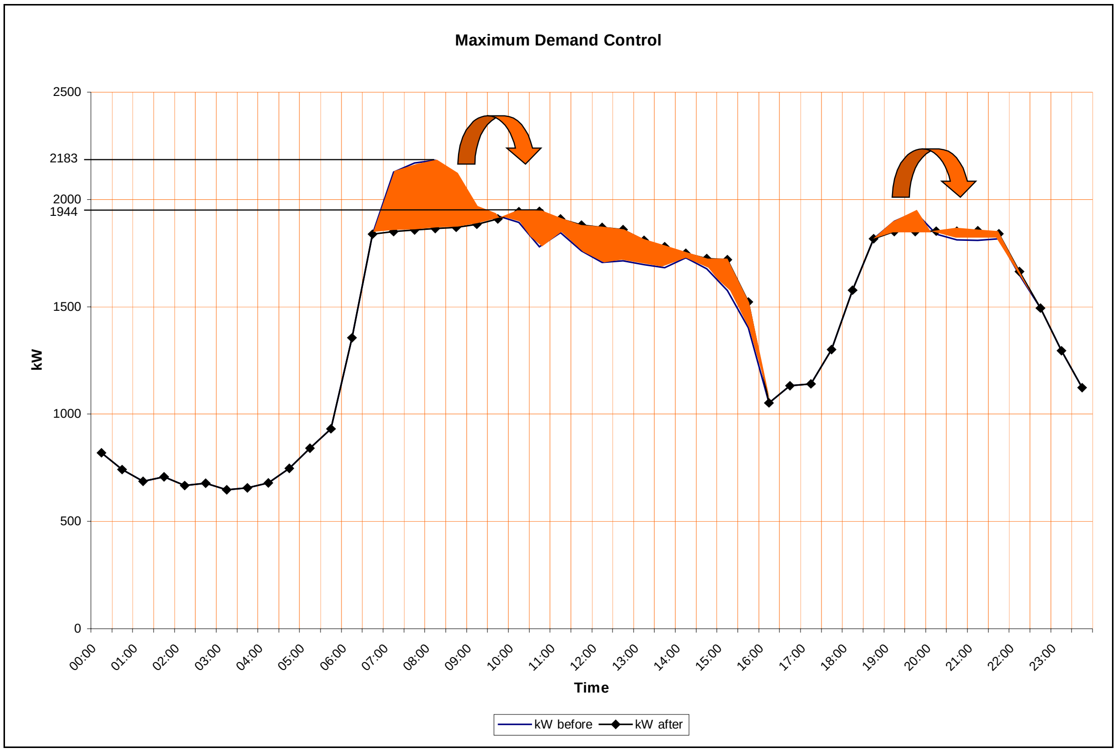
If the Power Factor is below 0.96 during the recorded maximum demand (at main incomer), Power Factor Correction becomes viable in certain cases. It, of course, all depends on the type of tariff and the amount charged for kVA or kVArh. The latter is used in some TOU tariffs and although its cost per unit is low, payback times need to be calculated. In most Consumption tariffs, Power Factor Correction will have no effect and should not be looked at.

4.2.3 Demand Side Management

This strategy is only applicable to sites that are on a Demand tariff. If the site has a high maximum demand during a short period (2 to 3 hours) a day, Demand Side Management (DSM) should be investigated.
The aim of DSM is to shift loads into periods where the demand is lower, causing the maximum demand to be lower. Typical sheddable loads are hot water plants (domestic geysers, boilers, hot water heat pumps, etc.) because turning them off for several (up to 15) minutes will not cause any discomfort. Also pumps that empty reservoirs can be turned off for a period of time without causing floods (make sure the overflow protection overrules the DSM).
DSM can be achieved through 2 methods:

- If the load profile is predictable, the time when the maximum demand will occur is always the same. Therefore a simple timer-like device can be used to turn the load off for a set percentage of time during that period. The devices can be mounted in the electrical circuit of the load and can work stand-alone. The time will have to be checked on a regular basis to ensure that the load is shedding at the correct time.
- If the time that the maximum demand occurs is not predictable, a different approach is necessary. The load at the main incomer (near the electricity meter) has to be measured real-time and action is required once the load exceeds a setpoint. The controller will have to switch off (using load switches) dedicated (sheddable) loads. Communication between the controller and these load switches is needed. Communication can be achieved using hard wiring (simple relays that switch off the load), radio communication or ripple control. Ripple control is a method of adding a signal to the electricity supply, which is recognised by the remote load switches. For small sites, hardwiring is the preferred method. For medium sized sites, radio communication is the answer. For large sites (municipalities or suburbs) both radio communication and ripple control are viable solutions.

In graph 3 the effect of DSM is shown. Note again that this strategy does not reduce the electricity consumption; it merely shifts it to a different period, when the load is lower.



Graph 3 Load shifting

4.2.4 Air Conditioning

Air conditioning installed in a commercial building will often contribute 50% towards the maximum demand (kVA) of the building and 35% towards the consumption (kWh) of a building. There are many strategies that can be implemented to reduce the consumption and demand of an air conditioning system, some of which are described below.

4.2.4.1 Fresh Air Quantities

Fresh air is introduced into a building to maintain good indoor air quality and prevent stuffiness and a build-up of odours. Increasing fresh air volumes normally improves indoor air quality, but it also adds to the energy consumption of the air conditioning plant.

If the fresh air volume supplied to the building is fixed and cannot be varied according to the outside air temperature, it should be set at that prescribed according to the National Building Regulations SABS 0400 and as summarised in the Table 2.

Occupancy	Class	Design population	Minimum Ventilation Requirement
Entertainment and Public Assembly	A1	Number of fixed seats or 1 person /m² if there are no fixed seats	3.5 l/s per person
Theatrical and Indoor Sport	A2	Number of fixed seats or 1 person /m² if there are no fixed seats	3.5 l/s per person
Places of Instruction	A3	1 person / 5m²	7.5 l/s per person
Places of Worship	A4	Number of fixed seats or 1 person /m² if there are no fixed seats	3.5 l/s per person
Exhibition Hall	C1	1 person / 10m²	3.5 l/s per person
Museum	C2	1 person / 20m²	3.5 l/s per person
Hospital	E2	1 person / 10m²	5.0 l/s per person
Offices	G1	1 person / 15m²	5.0 l/s per person

Table 2. Required Fresh Air Quantities

Fresh air volumes in excess of the above (Table 2) volumes could lead to excessive energy consumption by the air conditioning plant.

Action: Calculate required amount of fresh air and verify on-site.

4.2.4.2 Economy Cycle

In some instances, the air conditioning system may be designed or can be retrofitted so that the fresh air quantity can be varied. This can be effectively used to reduce the energy consumption of the air conditioning plant during intermediate weather.

Consider a scenario where you have an office building with many internal offices or offices with high equipment loads. In these instances, the building may need cooling due to the internal heat loads, even when it is cool outside. Instead of running the mechanical refrigeration equipment to cool these areas, one can simply supply the cool fresh air from outside to these areas and switch the refrigeration plant off. To achieve this one needs to have a fresh air system that can vary from minimum volume during hot weather to full volume during cool weather. This is referred to as an economy cycle. Also required is a relief system so that when the air conditioning system switches to full fresh air, the relief air system provides exhaust from the building so that an air balance is maintained in the building.

Good applications for economy cycles are as follows:

- Office buildings with deep internal space
- Rooms with high equipment heat loads
- Facilities with high occupancy rates, such as cinemas, concert halls, airports, shopping centres and casinos.

Action: Check if the economy cycle is controlled by measuring enthalpy. If this is the case, check the correctness of the humidity sensors. Also check if systems without economy cycles can be retrofitted to include an economy cycle.

4.2.4.3 Humidity Control

Humidity control is important in some air conditioning applications, such as in computer or electronic equipment rooms and book archives. The removal of moisture from air is generally done by cooling the air to its dew point, at which time water starts to condense out of the air and it may be drained away. This process is normally achieved using a fin and tube heat exchanger. The process of cooling the air, passing through the heat exchanger, to its dew point is energy intensive and if not designed or controlled properly, may be a large waste of energy.

Consider the example below where all the air being supplied into a book archive is passed through one cooling coil. The source of the increased moisture coming into the building is from the fresh air where it mixes with the return air before passing through the coil. The ratio of fresh air to return air is approx 10%/90%. Because of the moisture coming in through the fresh air, the main cooling coil must cool all the air supplied to the building down to below its dew point (10°C) so that the water can be condensed out. The air at 10°C is then too cold to supply to the building as it will result in the rooms in the building being too cold. One then needs to reheat the air to raise its temperature to an acceptable supply air temperature so that the rooms in the building are not overcooled. This simultaneous heating and cooling is a major waste of energy.

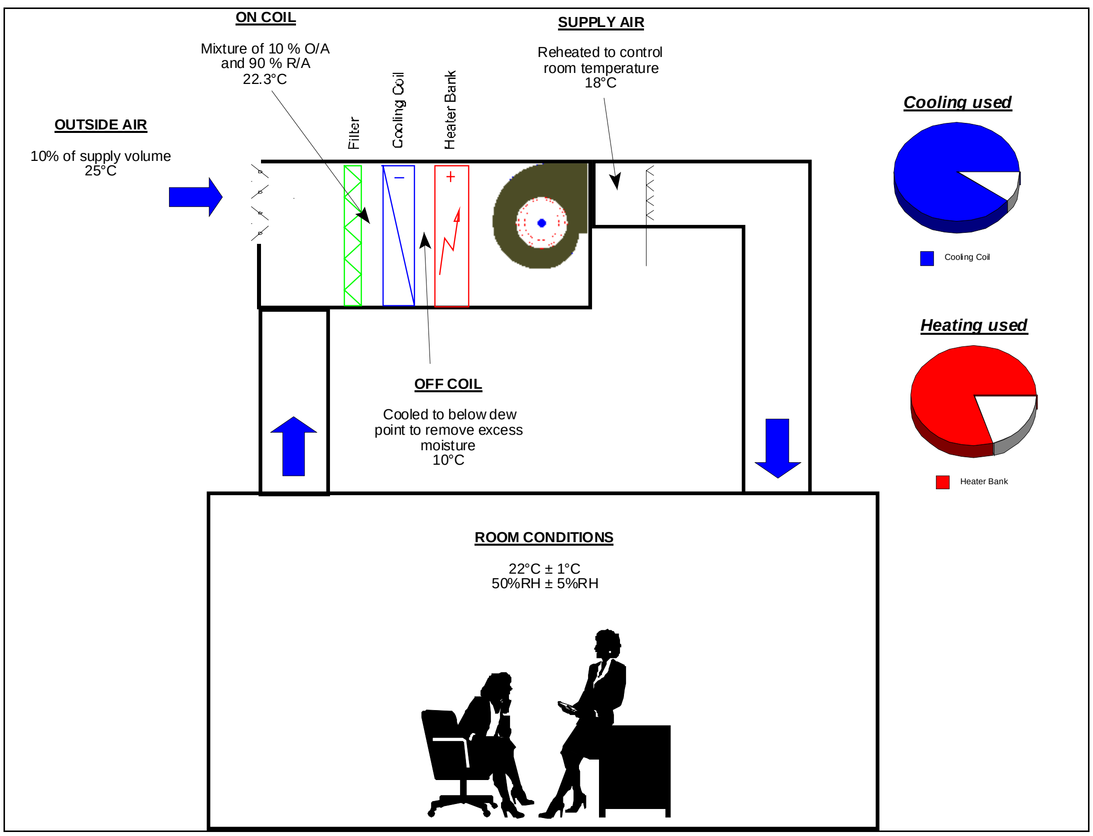


Figure 1: Dehumidification with reheating

An alternative method would be to remove the moisture from the fresh air before it is mixed with the return air as indicated in Figure 2. Only the fresh air, which is 10% of the total air volume, needs to be cooled down to 10°C so that the water condenses out. When the cold dry fresh air at 10°C then mixes with the return air at 22°C, minimum cooling is required to achieve a supply air temperature of 18°C, and no reheating is required.

An alternative method of dehumidifying air is via a heat wheel which makes use of a desiccant substance to absorb the moisture. Heat wheels are recognised as being a very energy efficient method of dehumidifying air and are described later under Heat Recovery (see 4.5.11)

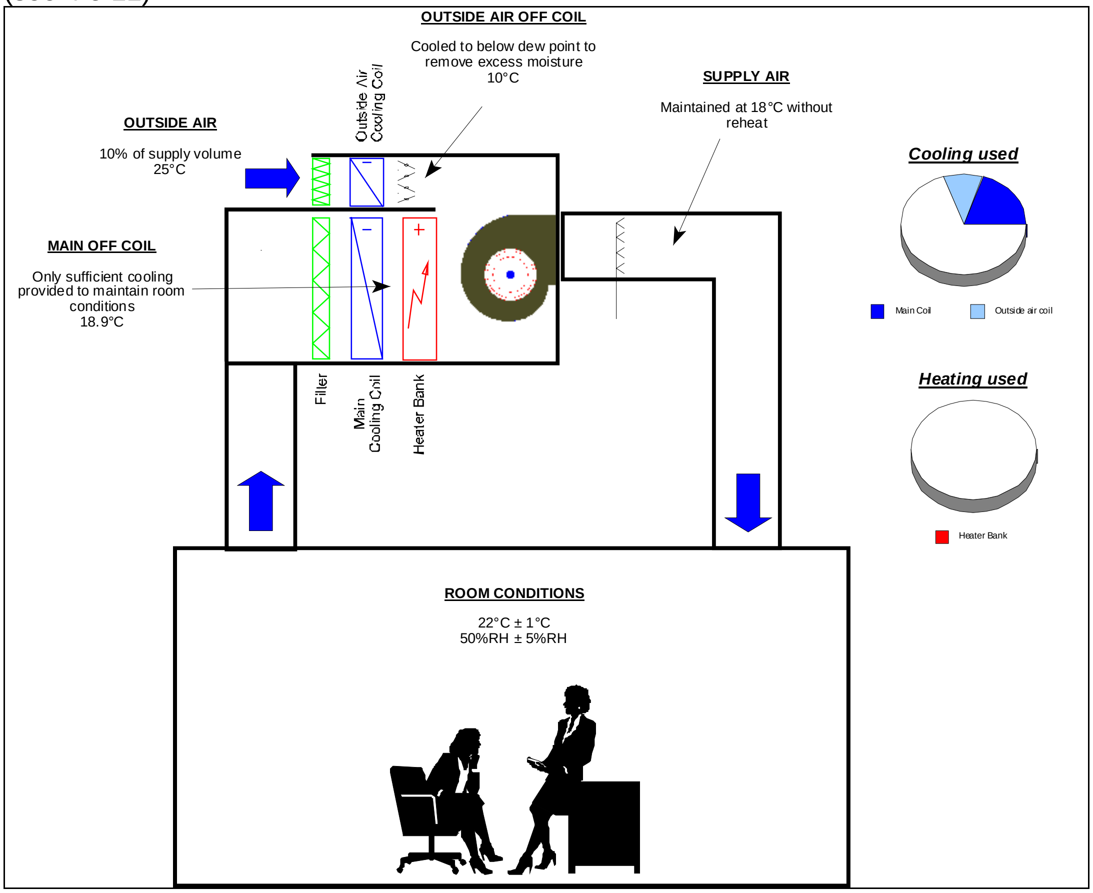


Figure 2: Dehumidification without reheating

Action: If there are humidity controls, check the functioning of the humidifier and its humidity sensors. Check if there is any simultaneous heating and cooling.

4.2.4.4 Filter Pressure Drops

Dirty filters in air conditioning systems normally result in an increase in fan power and a drop in the effectiveness of the air conditioning system.

Ensure that pressure gauges are always installed across major filter banks and that clean and dirty indicators are marked on the gauges. Filters should be inspected regularly and cleaned as part of routine maintenance.

Consideration should also be given to increasing the size of filter banks to reduce the pressure drop across them and hence reduce the fan energy.

Action: Verify if filter pressure drops are too high because of dirt. Also check with Maintenance Department, whose (if anybody's) duty it is to clean the filters.

4.2.4.5 Damper Pressure Drops

Duct mounted dampers in air conditioning systems are often poorly set during commissioning or after commissioning. It is easier for an installer to close down a damper to achieve the correct air quality than to slow down the supply fan.

If you discover dampers that are hissing and are more than 50% closed, it may be possible to re-balance the system with a slower fan speed and dampers that are set more open. Slowing the fan speed will reduce the power consumption of the fan significantly.

4.2.4.6 Variable Speed Drives

Many commercial buildings are fitted with variable volume air conditioning systems. This means that as the cooling load in the building drops, the volume of air supplied by the system drops. The reduction in supply air volume can be achieved in different ways.

In old buildings, the volume is reduced by inlet vane control dampers on the supply air fan or volume control dampers in the supply duct. A much more energy efficient method of doing this is to fit variable speed drives to the supply fan which act to slow down the fan rather than throttle it. Table 3 shows the difference in energy consumption of the fan at 50% supply volume with various volume control techniques.

Fan Energy Used at 50% Volume Flow	
Constant Volume	
Variable Volume with Damper Control	
Variable Volume with Inlet Vane Control	
Variable Volume with Variable Speed Control	

Table 3. Overview of energy consumption of various VAV controls

It may also be viable to convert a constant volume air conditioning system to variable volume and fit variable speed drives to the supply fans.

Variable speed drives can also be fitted to pumps with similar success.

Action: Check if the plant runs on partial load for long periods; this is the first indication if VSDs are suitable.

4.2.4.7 Optimum Stop/Start

The start and stop times of an air conditioning system will have a dramatic influence on the energy consumption and demand of a building. Here are a few common faults.

- The system is started too early, wasting energy on air conditioning a building that is not occupied.
- The system is started too late, causing a high load on the system and resulting in an artificial peak and high maximum demand charge in the morning.
- The system is stopped too late, wasting energy in air conditioning a building that is not occupied.

Adaptive controllers can be installed which specifically optimise the stop and start times of large central plants. Alternatively, one needs to strike a balance between energy efficiency and user comfort.

It may also be possible to stop a central chilled water plant earlier than the supply fans and make use of the thermal inertia in the chilled water system.

Another strategy which goes hand in hand with stop/start is pre-cooling where cool outside air is supplied into the building in the early hours of the morning (say, between 3:00 a.m. and 6:00 a.m.) to pre-cool the building structure, saving on mechanical cooling later in the day.

4.2.4.8 Off Peak Operation

Energy is often cheaper at night, either because you avoid a demand charge or because it falls into an off peak period on a time of use tariff. In order to make use of off peak energy, the air conditioning system must incorporate thermal storage such as ice storage, eutectic storage or other thermal storage media. A detailed analysis of the building's thermal performance must be carried out in order to optimise off peak energy and thermal storage.

4.2.4.9 Chiller Configuration and Sequencing

The sequencing of chillers and selecting the lead and lag machine plays an important role in optimising the energy consumption of a chilled water plant. If the plant comprises different sizes or types of chillers, the supplier information must be analysed to determine which are the most efficient machines.

The efficiency of chillers also drops off as they unload. It is therefore always better to achieve a system where there are fewer chillers running at high load rather than many machines running at low load. Two machines at 80% are better than four machines at 40%, for example.

The energy consumption of a chiller also reduces as the leaving chilled water temperature setpoint increases. It is often possible to reset the leaving chilled water temperature setpoint during the cooler months of the year and achieve energy savings.

4.2.4.10 Cooling Towers

Cooling towers provide a means of heat rejection from a building and because the amount of heat extracted from a building varies, cooling towers need to be controlled to match the heat rejection requirements. The three main methods of controlling cooling towers and the condenser water temperature are:

- Bypass – the cooling tower fans run continuously and a bypass valve allows condenser water to bypass the tower to maintain condenser water temperature.
- Cycle Fans – the cooling towers receive a continuous flow of condenser water and the cooling tower fans cycle on and off to maintain the correct condenser water temperature. Sometimes two-speed motors are used on the fans so they can switch between low and high speed in addition to on/off.
- Variable Speed Fans – the cooling towers receive a continuous flow of condenser water and variable speed fans maintain the correct condenser water temperature.

Of the three options, the first is the least energy efficient and the last is the most. A detailed simulation of a building's heat rejection requirements should be conducted in order to evaluate the three options properly.

It should also be recognised that, within limits, lowering the condenser water temperature from the towers lowers the chiller input power. In some instances, the reduced chiller consumption more than compensates for the added cooling tower fan power. The minimum condenser water temperature that can be used is dependent on the type of chiller and the manufacturers' requirements, so these must be checked before making changes. Some chillers such as centrifugal chillers benefit greatly from low condenser water temperatures under part load as this minimises the potential for surge, whereas some screw chillers rely on a higher condenser water temperature to create a pressure differential for oil circulation. Care should be exercised when making changes to condenser water temperature control.

4.2.4.11 Heat Recovery

Heat recovery is a means of saving energy by exchanging heat between the exhaust air of a building and the incoming fresh air. There are four main methods of achieving this heat recovery, as described below.

a) Thermal Wheel

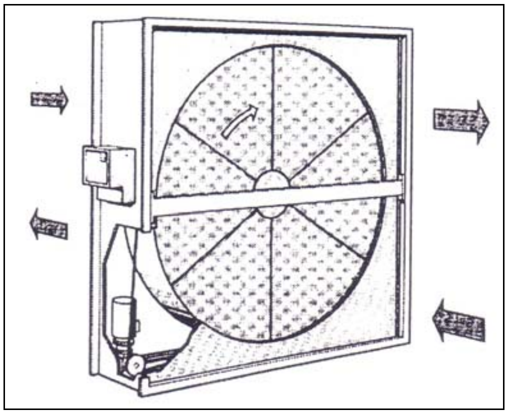


Figure 3: Thermal Wheel

As indicated in Figure 3, a rotor with a permeable storage mass is fitted in a casing. The rotor is driven by a motor so that the exhaust air and then the fresh air are alternately passed through each section. The heat recovery efficiency is usually 70% to 75% and the air pressure drop ranges between 150 Pa and 250 Pa.
Thermal Wheels are preferred if:

- Not only heat but also humidity transfer is desirable.
- A high heat recovery efficiency is called for.
- The airflow rate is high (generally >4.2 m^3/s), and small casing dimensions are required.
- Minimum cost with high airflow rates.

b) Plate Heat Exchanger

As indicated in Figure 4, the exchanger consists of thin plates that are mutually sealed so that the fresh air and exhaust air exchange heat without mixing.

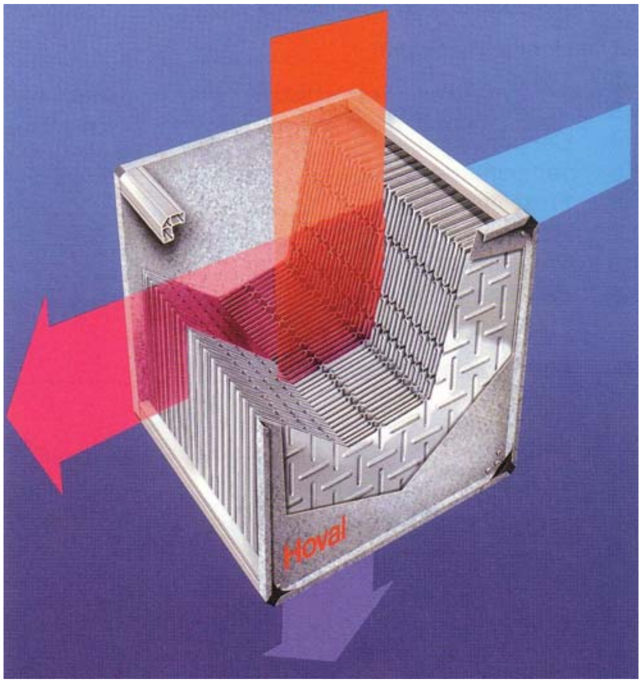


Figure 4: Plate Heat Exchanger

The heat recovery efficiency is usually 50% to 60%, and the pressure drop ranges between 150 Pa and 250 Pa.

Plate heat exchanges are preferred if:

- The transmission of humidity is undesirable (e.g. tumble drier heat recovery).
- Contamination of the fresh air is not permissible.
- High operating reliability is required.
- The air flow rate is below 6.0 m³/s and low costs are required.

c) Heat Pipe

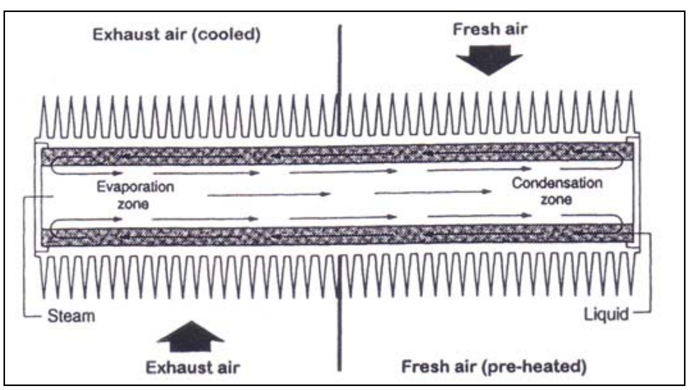


Figure 5. Heat Pipe.

A casing, which is divided in the middle, contains several rows of evacuated tubes. The tubes are fitted with fins, for better heat transfer, and they carry a refrigerant to drive the heat transfer from exhaust air to fresh air.

The heat recovery efficiency is generally about 25% to 35% and the pressure drop ranges between 200 Pa and 400 Pa.

Heat pipes are preferred if:

- The transfer of humidity is undesirable
- No contamination of the fresh air is permissible
- Temperatures are very high
- Small unit dimensions are required.

d) Run-around Coils

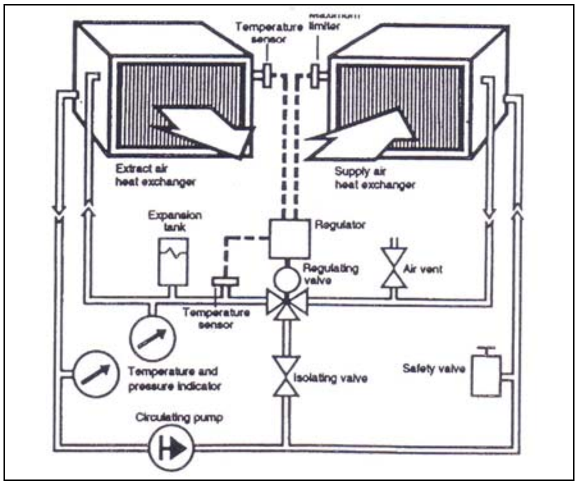


Figure 6. Run-around Coil

The coil in the exhaust air and the coil in the fresh air are linked with a closed water circuit and circulation pump. The heat is first transmitted from the exhaust coil to the water circuit and then to the fresh air via the second coil. The efficiency is usually 35% to 45% and the air pressure drop ranges between 150 Pa and 250 Pa.

Run-around coils are preferred if:

- The exhaust air and fresh air ducts are far apart.
- Exhaust air and fresh air must be absolutely isolated.
- Small unit dimensions are required with high airflow rates.

4.2.4.12 Equipment Insulation

The insulation of air conditioning equipment is important to ensure that heat is efficiently transferred to its desired place and not lost along the way. The following insulation areas should be checked during an energy audit.

- Chilled or hot water piping insulation.
- Supply air ducting insulation.
- Air handling unit insulation.
- Hot/chilled water storage tank insulation.

4.2.4.13 Simultaneous Heating and Cooling

Simultaneous heating and cooling has been discussed briefly under humidity control in this document. Another frequent occurrence of simultaneous heating and cooling is in systems where electric re-heaters are installed in diffusers of an air conditioning system. This is generally done with variable volume air conditioning systems and sometimes with constant volume systems. The reason why heaters are fitted to the diffusers is to control room temperature. If the supply air coming to the diffuser is so cold that it tends to overcool the room, the heater is activated to raise the temperature in the room back to the thermostat's setpoint. This means you have used energy to cool the air down in the first place, at a central plant, and then you have used an electric heater to heat it up again.

When this is encountered, the control philosophy of the central plant must be investigated to see if the supply air temperature can be reset or raised when the cooling load is low. Also investigate if the supply air temperature to perimeter offices can be controlled separately from internal offices because they have different load profiles.

4.2.5 Domestic hot water

- Check hot water temperatures on geysers and other domestic hot water plants. 60°C is enough for domestic purposes. Do not set temperature lower, as this enables bacteria growth.
- Verify if hot water cylinders are insulated and check the state of the insulation.
- Check the flow rate of showers; more than 12 litres/minute is too much, and if the shower is frequently used it might pay back to install flow restrictors or water saving showerheads from an energy saving point of view.

4.2.6 Fuel Source Conversion

From an environmental point of view, heating should never take place using electricity. Electricity plants produce electricity with an efficiency of 35%, so coal fired boilers with an efficiency of only 50% still produce less CO_2 compared to electricity. Modern fossil fuel burners can easily achieve efficiencies of around 80%.
From a cost point of view it is not so clear, however. Refurbishing an electrical boiler to a fuel-fired boiler is hard to pay back. Therefore it is necessary to optimise existing fuel-fired boilers:

- Investigate percentage of excess air in flue gas; reduce to a minimum.
- Investigate viability of stack gas heat recovery, or relocation of combustion air intake.

Partly refurbishing a boiler might be viable using electrical heating elements to produce steam at night and a fossil fuel burner to produce steam during the day.

4.2.6.1 Steam

- Investigate jammed steam traps.
- Check if condensate can be recovered.
- Inspect if there are dead steam lines (i.e. steam pipes that are no longer in use) and isolate or remove them.
- Verify viability of installing heat exchangers instead of direct use of steam.
- Check if all steam pressures are according to design.

4.2.6.2 Pump efficacy

Although most pumps form part of the Air Conditioning installation this paragraph is broader as it also includes river water pumps, reservoir pumps, drinking water pressure boosters, etc.

- Investigate if pressure set points are correct, and not too high.
- Investigate the possibility of Variable Speed Control (see 4.5.6.).

4.2.6.3 Compressed Air

- Investigate usage-flow rate (at night when site is not operating) to calculate leaking percentage.
- Study the influence when the air intake is relocated to a colder spot (e.g. outside air vs. plant room air).

4.2.7 Building

The shape, orientation and envelope of a building play an important role in its energy consumption and demand. When auditing an existing building, there is generally not much one can do about its shape and orientation, but one can address problems with the building envelope.

4.2.7.1 Thermal Insulation

In South Africa, the roof of a building can significantly increase the cooling load in summer and become a major source of heat loss in winter. In general, all roof structures above conditioned or occupied areas should be insulated. If insulation is not installed, installing it could prove to be a cost effective method of reducing energy bills. The various methods of insulating roofs would include:

- Above a concrete roof: rigid insulation laid above the waterproofing with stone chips above.
- Above a concrete roof: rigid underscreed insulation with waterproofing above or below.
- Below a pitched roof: rigid or bubble insulation above the purlins and below the sheeting or tiles.
- Below a pitched roof: fibreglass insulation laid above the ceiling boards

In some instances, installing insulation in the façade of the building may also prove to be viable, particularly if the façade is constructed from composite materials.

4.2.7.2 Window Shading

Solar radiation penetrating through a window into a building also contributes significantly to the cooling load of a building during summer. External shading devices are the preferred method of reducing solar load because they prevent the sun from striking the building. If external shading devices are carefully designed, the can also take the lower solar altitude in winter into account and allow solar radiation to passively heat the building in winter. An alternative to external shading is solar control films applied to the glass or solar control glass. An analysis of the cooling load in a building should be done to assess the significance of solar heat load in a building and the benefit of external shading.

4.2.7.3 Infiltration

A poorly sealed building will allow an excessive amount of outside air into the building when the wind blows. This in turn acts to overload a cooling or heating system in the building, particularly during extreme weather. If you can feel a draft coming through any part of the façade of a building when a moderate wind is blowing, attention needs to be paid to reducing the infiltration rate of a building.

4.2.8 Plug Loads

Appliances that are connected to electric outlet sockets can contribute significantly to the electrical load of a site. Especially offices and residential sites can have high plug loads occurring simultaneously, therefore creating demand spikes.

The problem, however, with plug loads is that they are turned manually and leave little room for automation. Awareness campaigns are the key solution to reduce plug loads, teaching users to turn off equipment if it is not used. Various appliances have energy saving modes as a standard feature; these should be activated as much as possible.

4.3 Stage 8; Baselines

Baselines are references from which future energy savings will be calculated. The calculation of baselines is described in Document 4: Measuring & Verification. The Consultant will have to calculate these figures and inform all parties involved (i.e. Client, ESCO, User Department), who will have to give approval. Once approved, the Consultant forwards the baseline to the ESCO that carries out the Detailed Audit. The baselines will be mentioned in the Detailed Audit by the ESCO.

The unit used as a baseline is the same as the energy source as it is measured. For electricity this is kWh and kVA. For coal, paraffin and LPG it is usually in kilograms or tons. Diesel is normally measured in litres.
The Baseline should also include the amount of (tons) CO_2 produced. This is required to calculate the reduction of greenhouse gas (=CO_2) emission as a result of energy management opportunities. Note that electricity does not produce CO_2 when it is consumed, but fossil fuels were used when generating the electricity with a certain efficiency.

In Table 4 an overview is given of energy sources and corresponding CO_2 emissions for South Africa.

Energy sources	**kg CO_2 / unit fuel**	**kg CO_2 / GJ***
Electricity	0.77 kg CO_2/kWh (Eskom) 0.89 kg CO_2/kWh (EIA)	213.89 kg/GJ (Eskom) 247.22 kg/GJ (EIA)
Distillate Fuel (No.1,2,4 fuel oil and diesel)	2.68 kg CO_2/litre 3.14 kg CO_2/kg fuel	69.38 kg/GJ
Residual Fuel Oil (No. 5 and 6 fuel oil)	3.12 kg CO_2/litre 3.12 kg CO_2/kg fuel	74.77 kg/GJ
LPG	1.54 kg CO_2/litre	59.78 kg/GJ
Propane	1.52 kg CO_2/litre	59.84 kg/GJ
Natural Gas	1.93 kg CO_2/m^3_n	50.34 kg/GJ
Bituminous Coal	2465.61 kg CO_2/ton fuel	88.27 kg/GJ
Sub-Bituminous Coal	1857.91 kg CO_2/ton fuel	91.45 kg/GJ

Table 4. CO_2 emission of energy sources
* GJ values are based upon Higher Heating Values

Table 4 was compiled using the following sources:
- GHG Protocol, Eskom environmental report, 2000 figures, Agama
- CO_2 calculation tool from www.ghgprotocol.org (Energy Information Agency EIA)

4.4 Stage 9; Detailed Audit Report

The report containing the findings of the Detailed Audit should have a standard structure to facilitate verification by the Consultant. The following paragraphs should be included regardless of whether they are applicable to the studied site. Portions not applicable to the site, should be identified with the words “Not Applicable”.

4.4.1 Site Summary

- Site’s physical address
- Contact person(s), telephone number(s), fax number(s), e-mail address(es), etc.
- Size of site; square metres of floor area
- Baseline

- Energy indices from Preliminary Audit
- Occupancy numbers at time of Detailed Audit

4.4.2 Summary of Walkthroughs

At least every item of paragraph 4.2 needs to be mentioned if it is present on-site. All additional relevant equipment that has an effect on the energy consumption should be included.
All items that were investigated as potential Energy Management Opportunities (EMOs), should be mentioned, regardless whether they are viable.
All potential EMOs that have been identified as viable should be marked and have a reference to the detailed energy saving calculation (see 4.4.3.).
A short example of this summary sheet is given below:

Description	Present on site?	Potential EMO	Viable EMO	Reference
Lighting	Yes	Yes	Yes	3.1 Retrofit
Power Factor Correction	No	Yes	Yes	3.2 PFC
Demand Side Management	N/A	No	No	
Air Conditioning: Fresh Air Quantities	Yes	No	No	
Air Conditioning: Economy Cycle	No	Yes	No	

4.4.3 Energy Saving Calculations

For every viable EMO a calculation has to be presented in the Detailed Audit Report. This calculation should clearly show the following predictions:

- Energy savings
- Demand savings
- Reduction of CO_2 emissions
- Energy cost savings

The technical lifetime of the product needs to be included.
There is no standard template for energy savings calculations, such calculations are an engineering process that the ESCO is capable of performing. They should, however, be comprehensive and transparent, so that the Consultant can verify them easily.

4.4.4 Equipment Specifications

All specifications and available documentation of the proposed equipment need to be included. The Consultant can check whether they comply with the appropriate standards.

4.4.5 Impact on site personnel

Although the ESCO can only submit EMOs that do not affect the level of service on-site (i.e. affect comfort), some EMOs will affect the operation of certain equipment. Maintenance departments and site personnel will need to be informed on how to use the new equipment.

4.5 Stage 10; Approval Consultant

The Consultant will judge the report on correctness and will only approve the proposed EMOs if it is certain that all calculations and assumptions made in the Detailed Audit Report are true. The Consultant will then compile a fact sheet consisting of a summary of all approved EMOs.

APPENDIX A: ENERGY INDICES

	MJ/m2/an LOW	MJ/m2/an MEAN	MJ/m2/an HIGH	VA_avg/m2/mth LOW	VA_avg/m2/mth MEAN	VA_avg/m2/mth HIGH
Educational	310	462	854	23	37	82
Hospital	N/a	1123	N/a	N/a	70	N/a
Industrial (workshops, naval, air force)	278	474	1108	17	33	72
Library / Archive	418	640	1069	25	34	52
Military Radio Station	3243	4533	6524	194	324	453
Office (intensively occupied)	396	1010	1513	59	90	197
Office (low occupancy)	217	466	712	19	35	77
Prison	239	534	889	15	28	56
Residential	201	435	735	13	22	36

The above table was compiled using real figures of buildings within South Africa. The buildings are mainly located in the Western Cape and Gauteng. The dispersion of collected data was bigger than the variance in consumption due to geographical location.

Capacity Building in Energy Efficiency & Renewable Energy

Report No. 1 Auditing

APPENDIX B: WALKTHROUGH SHEETS

BUILDING DETAILED WALKTHROUGH AUDIT

Compiled By:
Date:

Metering point	
Metering Authority & Tariff	
Contact person on site	Phone

BUILDING DETAILS

Building Name				
Building Address				
No. of floors	Usage	Gross Area m^2	Nett Area m^2	
Equip. Loading	People Density			
Occupation Week:		Sat:		Sun:
HVAC System				
Remarks				
Lighting Area 1: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 2: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 3: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 4: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:

Building Name				
Building Address				
No. of floors	Usage	Gross Area m^2	Nett Area m^2	
Equip. Loading	People Density			
Occupation Week:		Sat:		Sun:
HVAC System				
Remarks				
Lighting Area 1: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 2: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 3: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:
Lighting Area 4: Description			Floor Area	m^2
Type of fitting:	No of:	Tubes/fitting:	W/Tube:	Lux:

BUILDING DETAILED WALKTHROUGH AUDIT

Compiled By:
Date:

ELECTRICAL SUPPLY

Incoming Supply	Metered at audit	V	A	A	A
Power Factor Correction					

HVAC EQUIPMENT

Description				
Areas Served				
Equip. Location				
Make				
Model				
Serial No.				
Rated Performance				
Rated Consumption				
Power Supply				
Running Hours Week Days Saturday Sunday				
Remarks Condition Level of Maint. Visual Problems Operator Concerns				
Description				
Areas Served				
Equip. Location				
Make				
Model				
Serial No.				
Rated Performance				
Rated Consumption				
Power Supply				
Running Hours Week Days Saturday Sunday				
Remarks Condition Level of Maint. Visual Problems Operator Concerns				

BUILDING DETAILED WALKTHROUGH AUDIT

Compiled By:
Date:

DOMESTIC HOT WATER PLANT EQUIPMENT

Description				
Areas Served				
Equip. Location				
Make				
Model				
Serial No.				
Rated Performance				
Rated Consumption				
Power Source				
% Loaded at Audit				
Running Hours Week Days Saturday Sunday				

GENERAL REMARKS

APPENDIX C: FLOOR AREA MEASUREMENT METHOD

Calculating nett floor areas is based upon the following criteria:

Total building floor area is measured from the inside finished surface of the permanent outer building walls. Areas that will be deducted are:

- Escape stairs
- Shafts (for cabling, ducting, piping, etc.)
- Stairs and lifts (including landing area) that do not exclusively serve 1 floor[1].
- Parking (basement or above ground)
- Entrance foyers
- Service areas (cleaners storerooms, electrical service room, plant rooms) that serve multiple floors[2].
- Patios

[1], Stairs and lifts are deducted in 99% of the cases. However, if there is one exclusive staircase for that floor, it is part of the nett floor area. An example would be a shop on the ground floor and an office on the first floor with its own entrance. The staircase leading to the office shall be part of the nett floor area.

[2], Service rooms that serve only that floor have to be included in the nett floor area. Examples are cleaners' storerooms, electrical service rooms with the distribution boards for only the same floor, air-conditioning plant rooms providing conditioned air for only the same floor.

The basic idea behind the measuring method and the allowed deductions is that, if the building should be used by multiple tenants, all shared facilities are excluded from the floor area for which the tenant is paying.