A Simple Guide to HVAC and Lighting Efficiency in Commercial Buildings

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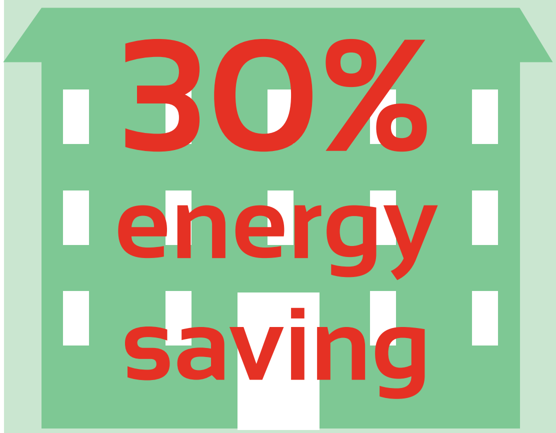
Introduction

This guide offers an overview of energy efficiency design and management interventions relating to Heating, ventilation and air conditioning (HVAC) and lighting in the commercial building sector. The information may be applicable to offices, large retail space or public buildings. All new buildings, additions and extensions must now comply with the energy efficiency requirements set out in the new SANS 204:2008 document. However, substantial savings may still be realized within the existing building stock. The information provided here aims to support building owners, developers and managers to take action to reduce their electricity consumption. An outline of the new SANS requirements are provided, as well as practical tips to ensure efficiency in the design, retrofit and ongoing management and maintenance of HVAC systems and lighting.



In fully air conditioned buildings the HVAC component ranges between 30 and 60% of the building's overall energy use. Lighting usually makes up between 20% - 30% of energy consumption. The two technologies interrelate: reducing lighting energy usage impacts directly on the HVAC system because of the heat generated by lights. Energy efficient lighting plus HVAC system improvements could halve the HVAC consumption. Lighting efficiency can achieve at least 40% efficiency in most buildings. With LED lighting technology, this can be even greater. **Together these interventions could result in total building energy savings of around 30%** of a typical office block or retail centre.

The Regulatory Environment: SANS 10400-XA and SANS 204

Both the SANS 10400-XA:2011 and SANS 204:2008 documents cover energy use in buildings. SANS 10400-XA supports the National Building Regulations which are mandatory. All new buildings must comply with the regulations, as must any extensions and additions to existing buildings. 10400-XA requires that new buildings comply with the energy efficiency requirements set out in 204.

SANS 204 has tables which stipulate the maximum energy demand and the maximum annual energy consumption for various kinds of buildings in the various climatic areas of South Africa. Any performance above these maxima must be justified through rational design by a competent person. Electrical appliances in new buildings are required to have an energy rating while thermal system equipment and components have to have insulation which minimises heat loss or gain.

Large emphasis is placed on building orientation and the thermal performance of the envelope (walls, roof, and windows) to be within the maximum allowable energy consumption. HVAC is the largest (up to 60%) energy consumer in most buildings and therefore represents a significant opportunity for contributing to the energy use reduction. A consequence of this is that building thermal performance will have to be modelled in advance, including that of the HVAC system, in order to obtain planning approval. This is a specialist task and the modellers will have to demonstrate competence and that they are using accredited software.

There is a specific requirement for solar heating of at least 50% of the hot water unless a competent person can prove that it is not feasible. In such cases it is necessary to make up the solar shortfall from waste heat recovery, heat pumps, or something similar. There is a more general requirement that renewable energy sources are to be maximised and can be utilised to mitigate where the maximum allowable demand and energy consumption have been exceeded.

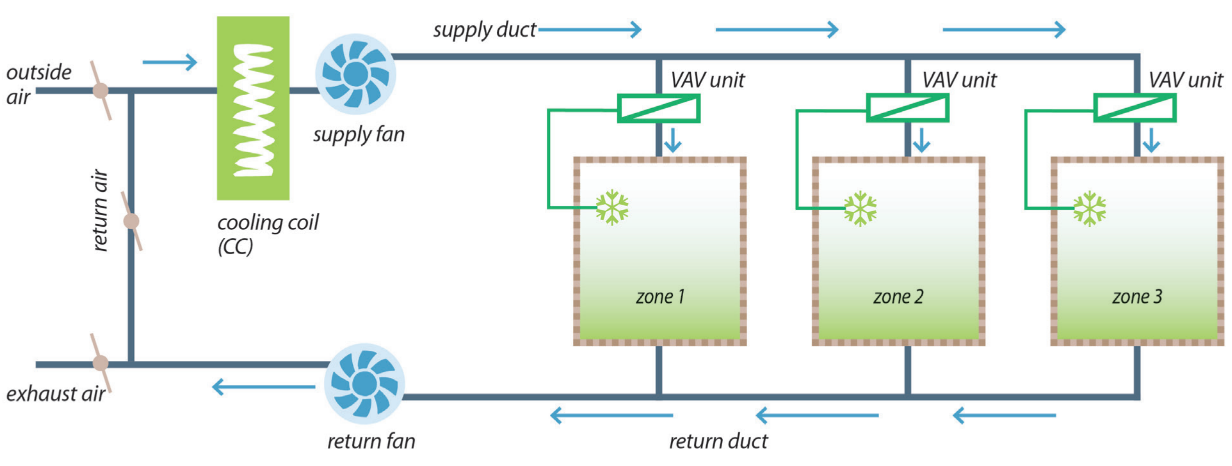
Local authorities require a certificate of compliance before they issue an occupancy certificate. Amongst the compliance requirements is one for artificially ventilated or air conditioned buildings to display their energy rating.

Air conditioning systems overview

Air conditioning of buildings is often referred to as HVAC – Heating, Ventilation & Air Conditioning. Given climatic conditions in South Africa most air conditioning systems are associated with keeping building occupants comfortable (cool) during summer. 'Comfort' is subjective but research has shown that most building occupants are comfortable between 20 and 26 deg C. The ventilation component is also important as many fully air conditioned buildings do not have easily openable windows and the HVAC system has to provide outdoor air to replace some of the internal air[1]. Areas of the country that are regularly subject to long cold periods would also need to consider heating requirements.

Air conditioning equipment ranges from a simple window- or wall-mounted unit for a small space, all the way to centralised systems for tower buildings. These larger systems can take one of several forms to remove the heat from the occupied space, or to warm them. They are usually named for their significant energy carrier – water, air, or refrigerant.

All-air systems use distributed chilled air or hot air if heating, running through large ducts, as the principal means of extracting (or providing) heat from a building. An advantage of these systems is that they can draw in air from outside of the building to refresh indoor air. **All-water systems** use distributed chilled water as the principal means of extracting heat from a building. For heating purposes, air or water in these systems can be heated by an electric element or steam/hot water from a boiler.



SINGLE DUCT, MULTIPLE ZONES, VAV SYSTEM

1 Systems may also include evaporative cooling – applicable in hot, dry environments, but this is not much in evidence in South Africa.

In refrigerant-based energy distribution systems cooling (and heating) is transported from external units to air distribution units within the building, by refrigerant flowing in small diameter pipes. The refrigerant flow rate is varied to provide more or less cooling or heating. The system is known as **Variable Refrigerant Flow – VRF, or Variable Refrigerant Volume – VRV**. These systems can operate as heat pumps – in heating mode they extract heat from ambient air and delivery it into the conditioned space.

Many large commercial buildings in South Africa now have a particular kind of all-air system known as VAV (Variable Air Volume). A VAV system delivers only as much conditioned air to the occupied space as is required by the temperature control in that space. ***A VAV system using an economy cycle with the supply air temperature scheduled according to the external ambient conditions is probably the most efficient system of all.***

However, different systems may offer other advantages. For example, Variable Refrigerant Volume (VRV) systems have reduced space requirements and can also more easily be installed in existing (occupied) buildings. VRV systems have gained much ground in recent years because of their perceived practical benefits.

Constant Air Volume (CAV) systems are not now as common as they once were. These systems have fixed (constant) low temperature supply air serving all spaces. Individual temperature control is effected by reheating the supply air as appropriate. The terminal heater is almost always a direct acting electric element. These systems have been regarded as very inefficient for some time and have usually been replaced by a much more efficient variable air volume system.

Each system type has various 'virtues and vices' from an efficiency perspective and the efficiency opportunities for each system type are outlined below.

Achieving HVAC efficiency

1. Building Design and construction features

Energy efficiency in buildings should start at the earliest possible point in the design process, i.e. the orientation of the building. This should be followed by including energy saving design features and high thermal performance construction materials. The design and construction features are usually difficult to change in existing buildings. However, one could look to retrofit multiple glazing for windows and external shading of windows as it is usually cheaper to prevent heat from needlessly entering a building compared with paying to run a cooling system.

2. HVAC system design and operation

Selecting a system and maximizing its efficiency

Each HVAC system has the capacity to be more or less efficient depending on the level of control attributes specified – and as a general rule, the more you pay the more you get.

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Window overhangs for shading

All-air systems: A benefit of the so-called 'all-air' cooling systems is their efficiency - they can introduce more outdoor air when the ambient temperature is low enough and while the occupied space still requires cooling. This 'free cooling' or 'economy cycle' operation minimises the use of the refrigeration equipment, saving energy and cost, by up to 15% in many cases. Some central plants have been installed without this simple feature and in most cases an appropriate retrofit can be made.

Another economy feature of an all-air system is to let the supply air temperature rise as the need for cooling reduces. Other systems do not have this control benefit. Again, this reduces the demand on the refrigeration system.

As with the less efficient CAV systems, the VAV system uses electric terminal reheaters but the air quantities during the heating mode are small. If heating requirements are substantial, boilers providing heat through steam or hot water could be considered.

VAV systems require a little more initial detail engineering design than, say, VRV systems.

All-water systems: These systems use distributed chilled water as the principal means of extracting heat from a building. As with the air system, the chilled water temperature can be set to rise as the building cooling requirement reduces.

All-water systems can usually switch from chilled water in the distribution pipes to hot water during periods requiring heating. However, in some cases the cold air at the room terminals is also reheated electrically, particularly during months of the year leading up to mid-winter.

Refrigerant-based energy distribution systems (VRF or VRV): In this case a variable quantity of refrigerant is pumped from external units to air distribution units within the occupied space. These systems do not have scope for free (ambient air) cooling or changing the fluid temperature, but some specification options do have a mechanism that sends heat rejected from one part of a building to another part that needs heating. Of course, if the whole building needs heating or cooling simultaneously, then this feature has no value.

A benefit of the VRF/VRV is that most of the systems have compressors with variable speed drives. This means the compressor power can be reduced as the demand for cooling or heating reduces.

It is beneficial to specify VRF/VRV systems to be of the heat pump variety in order to provide heating in cold months. Such systems are able to operate in the reverse mode, extracting heat from the outdoor environment and transferring it into the conditioned space. This is several times more cost effective than direct electric heating.

Temperature set point

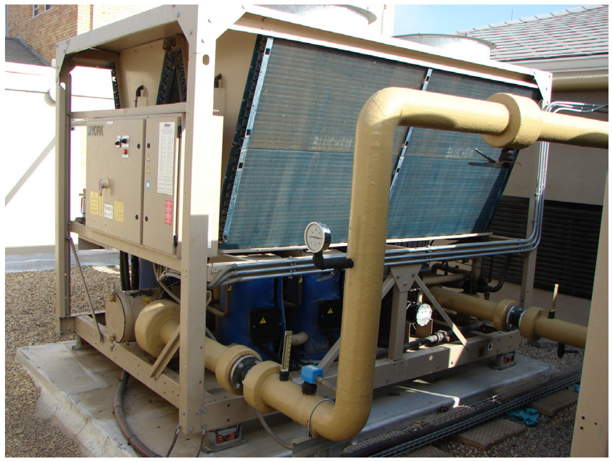
For example, if the external design temperature is taken as 30 deg C, there would be a 50% reduction in transmission and ventilation heat gain if the internal temperature was adjusted from 22 to 26 deg C.

Typically we dress according to the external temperature which means that it would not be a hardship to work in an office where the temperature set point was closer to 26 deg C than 22 deg C in summer. As a general rule, whatever the season, the internal temperature should be set within this range but towards the external temperature. This significantly reduces the workload of the cooling system, particularly in the cases where proportionately more outdoor air has to be introduced, such as in meeting rooms. The resetting of temperatures in any system may require additional controls, but this is not difficult or expensive.

Of course the first rule of energy saving is to switch off what is not being used. This should be the case for meeting rooms too, although this is often not possible because of ducting/circuit configuration. In this case, try to find the thermostat and turn it even further towards the outdoor temperature, leaving it in that position while the room is unoccupied. In winter heating is mostly required in the early morning or the evening and the heating system should not run for long. Overheating should be avoided.

Photo: Andy Cunninghame

Cooling towers



Air cooled chiller

Head pressure

All HVAC systems have external components (cooling towers or condensers) which have fans that remove the heat extracted from the occupied spaces. The systems would benefit from keeping the refrigerant temperature (or 'head pressure') as low as is reasonable. This is simply achieved by passing as much of the full design volume of air as possible through either the condenser or the cooling tower.

Heating

Heating requirements in South African buildings are relatively small and therefore most often provided by electrical elements (in air and water systems). Areas of the country that are subject to long cold periods may have fossil fuel boilers providing steam or hot water which would be supplied to heat exchangers located in the air conditioning system.

Thermodynamically it makes sense to supply heating requirements directly from burning fuel rather than using electricity. However, it is always a trade-off between higher equipment cost for the cheaper fuel and low equipment cost for electric heating. The level of heating demand is likely to influence choices here.

VRV/VRF systems should be of the heat pump type – able to operate in the reverse mode, extracting heat from the outdoor environment and transferring it into the conditioned space. This is several times more cost effective compared with direct electric heating.

Photo: Andy Cunninghame

Air cooled chiller – heat pumps

Air ducting and air handling units

Chilled water pumps

Photo: Andy Cunninghame

Buildings have internal heat gains which minimize the need for heating, particularly if the sun is shining. Intelligent air-based systems can be made to reduce or eliminate the need to heat outdoor air for the system during pre-occupancy heat up. Where it is necessary to have large volumes of outdoor air (e.g. meeting rooms) it would be advantageous to fit a heat exchanger between the air stream entering the building and the airstream leaving the building. In this way the exhaust ventilation preheats the fresh air required.

3. Building management and HVAC System Maintenance

The Carbon Trust in the UK has suggested that poorly maintained conditioning systems can add 30% to the bill.

Increasingly the data indicates that a great deal of energy savings arise from appropriate management and behaviour, rather than a technical 'fix'. Simple building management interventions, such as switching lights off, can significantly reduce the load on the HVAC system.

Maintenance of systems has been a neglected aspect in all air conditioning systems as there is only recently a growing awareness of the impact of good maintenance on performance. Clean filters and clean heat exchanger surfaces have a significant impact, not only on performance, but also on energy saving.

Developing Energy Management within your Business

The American Society of Heating, Refrigerating and Air-Conditioning Engineers states that ***energy management*** must be given the same emphasis as any other management discipline. Consequently, the functions of top management must be to:

- Establish the energy profit/cost centre in financial reporting systems
- Assign management responsibility for the maintenance programme
- Assign an energy manager and provide training
- Allocate resources such as staff and money
- Ensure that the programme is communicated throughout the organization
- Set clear programme goals
- Encourage ownership of the programme throughout the organization
- Continuously report on and analyse the programme
- Set up a feedback mechanism for continuous programme improvement

In addition to inculcating an energy efficiency culture amongst the tenants/ building users, other early tasks for an energy manager must be to evaluate the existing system, clearly defining and understanding the operation of the system and undertaking efficiency interventions outlined in the Building Energy Manager's Checklist. Experience indicates that it is very beneficial to establish benchmarks against which to monitor performance of HVAC and lighting. This enables managers to pick up performance 'outliers' and respond quickly to address the problem area.

Certain management and maintenance tasks may be outside the abilities of many energy managers. It is strongly recommended that independent advisors are engaged to undertake the analysis and quantify the specific opportunities. Be aware that advisors should be chosen from those that can demonstrate a systems approach, rather than someone with knowledge and experience focused on a particular component. Energy service companies can be found through the Eskom IDM or ESCO website links listed at the end of the document..

The challenges of tenanted buildings

In the instances of 'owner-occupier' buildings, owners are motivated to make energy efficiency investments as there is a direct reward, or return, for any investment – in the form of reduced expenditure on electricity. However, in tenanted buildings landlords may simply pass on as much cost as they can to tenants and therefore have little interest in reducing costs. Tenants may wish to bring down their operational costs, but have to petition owners, who have little interest in additional capital investment to achieve this. Tenants should consider:

- installing a meter to have more accurate bills for their own lighting and power;
- setting up a 'tenant association' to collectively bargain with the landlord to improve common and central services.

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Tackling HVAC efficiency: an energy manager's design and management checklist

Building and HVAC system design and retrofit

1. ***Reduce building heat gain through****: orientation of building, selection of high thermal performance construction materials and energy savings design features*.

2. ***Retrofit Energy Saving Building Design features.*** *These interventions are more cost effective than paying to remove heat through additional load on the HVAC system. Consider shading of windows, double glazing, insulation, and efficient lighting.*

3. ***System design:***

- *Don't overdesign the HVAC system.*
- ***Air systems:*** *ensure simple feature to introduce external air/ 'free air' to reduce load on refrigeration equipment is present.* **Can reduce energy consumption and associated costs by up to 15%.** *NOTE: this can be done as a retrofit.*
- ***Air and water systems:*** *design control to let the supply air or water temperature rise as the need for cooling reduces.*
- *ensure as much of the full design volume of air passes through the external cooling tower or condenser in order to keep the 'head pressure' as low as reasonably possible[2].*
- ***Refrigerant based:***
- *install mechanism to send heat rejected from one part of the building to another that requires heating;*
- *compressor power (generally variable speed drives) can be reduced as the need for cooling or heating reduces;*

Building and HVAC system management and maintenance

- *Switch lights off when not needed – this will reduce the buildup of internal heat and thus HVAC needs.*
- *Identify any building retrofit features that can reduce the need for air conditioning: efficient lighting, double glazing, window shading.*
- *Switch off HVAC (or reduce temperature if duct or circuit configuration don't allow) in rooms or areas not in use (e.g. meeting rooms).*
- *If the system is of the CAV type, try to have this converted to VAV*
- *Adjust temperature set point within the range of seasonal temperature and towards the external. The resetting of temperatures in any system may require additional controls but this is not difficult or expensive.*
- *Check and clean HVAC system filters and heat exchange surfaces –**if badly maintained they can add 30% to HVAC energy and cost***
- *Ensure that the controls are set with a wide enough band of temperature separating the cooling and heating functions, so that these two functions do not 'fight' each other.*
- *Fit outdoor air temperature scheduling to influence supply air and chilled water temperature as appropriate.*
- *Fit economy cycle operation to air handling units where space allows*
- *Develop and institutionalize a Building/HVAC Management system*

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2 Some refrigeration system are made to run at a constant 'head' or condensing temperature. The suggestion is to allow the temperature to fall by passing more cooling air through the condenser (=heat exchanger), thus allowing the compressor to work less hard.

Energy efficient lighting overview

A few decades ago commercial buildings were almost exclusively fitted with fluorescent lighting. There were occasionally incandescent lamps for specialist needs. The fluorescent lamps provided more light per unit of electricity than incandescent ones. There was only one tube diameter (T12 - 1.5 ins., or 38 mm). In recent years the tube diameter was reduced to T8 and T5 and the tubes have become more efficient. The new tube efficiencies have been further advanced by the advent of electronic control gear which replaced the old electro-magnetic control gear (required for starting the lamp). The overall saving in energy is about 40% for the same light output. T5 lamps have a lifespan of 20 000 hours and give over 80lm/W.

Compact fluorescent lamps (CFL) are used to replace single incandescent lamps. Not only is the CFL 75% more energy efficient, is can last up to 5 or 6 times longer (5 000 hours) than the equivalent incandescent unit. CFLs are more expensive than incandescent lamps but are cost effective when making the comparison on a life cycle basis.

Commercial buildings don't often have the need for high bay lamps, except, possibly, in double or triple volume areas. Traditionally high bay lamps have been mercury vapour units. A metal halide replacement would reduce the energy consumption by 50% for the same light output and quality.

The presence of light emitting diodes (LED) has increased significantly over recent years. They have a very high light output to energy ratio (35-88lm/W) and have a claimed lifespan of at least 25 000 hours. LEDs still need to be very carefully selected as there is a great range in the quality, especially when it comes to colour rendering and lifespan.

LEDs are commonly seen as single units for the replacement of small halogen lamps. Here a 5W typically replaces a 50W halogen. LEDs have also been made into strip lights as a replacement for fluorescent tubes. Lamp efficacies can be as high as 86lm/W and have a 40 000 hour life.

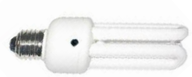
A very recent development of LED lighting has been a ceiling tile sized luminaire which readily replaces a 600 x 600 fitting containing, say, 4 x 18W T8 tubes. The light output is evenly spread over the whole face of the fitting. The claimed efficacy is 79lm/W.

Pay back periods when replacing lamps can often be as short as one year. The value depends on the efficiency of the lights being replaced. Probably most fluorescent tubes are now of the T8 variety. Improving such a system is slightly more costly as it probably means changing the ballast, a more difficult task since they do not clip out as do the tubes.

Great care must be taken when changing to energy efficient lamps as lighting is not just about energy. The many different designs now available can be used to great artistic effect. However, the science of lighting is essential when it comes to using light for productive purposes. Not only must the lamp output fall where it is needed but there must be the correct quantity of light and the light must also have the correct colour rendering.

Induction

LED



CFL

Overview of energy efficient lighting technology options for commercial building lighting.

Costs are set at 2012 values, are approximate and are VAT exclusive. It is also worth noting that T5 fluorescents require a new fitting – increasing the upfront retrofit cost of this technology; Led lamps can be fitted into the T8 fitting, where they must be fitted to bypass the ballast. The life span of the technology has not been included here. This must be factored in when comparing costs.

Conventional Light Fitting sets	Power (W) with CCG	Cost of fitting (multiple lamps)	Energy Efficient Fluorescent Fitting	Approx power saved (W) per fitting with FLlamp and ECG	Cost of Lamp	Approx Cost of entire new fitting for T5 lamps (T5 don't fit into T8 fitting)	Energy Efficient LED fitting (NB fits into T8 fitting, bypassing ballast, not T5)	Approx power saved (W)	Cost of lamp
2 x 18W Fluorescent tube (T8)	44	R 16.00	2 x 14W (T5)	14.52	R 32.00	R 700.00	2x 10W LED Tube	20	R 584.00
3 x 18W Fluorescent tube (T8)	66	R 16.00	3 x 14W (T5)	21.78	R 32.00	R 1 200.00	3 x 10W LED Tube	32	R 584.00
4 x 18W Fluorescent tube (T8)	88	R 16.00	3 x 24W (T5)	12.24	R 38.00	R 1 400.00	4 x 10W LED Tube	44	R 584.00
1 x36W Fluorescent tube (T8)	44	R 18.00	28W (T5)	14.52	R 42.00	R 850.00	1 x 18W LED Tube	16	R 802.00
2 x 36W Fluorescent tube (T8) - with CCG and ECG	88	R 18.00	2 x 28W (T5)	29.04	R 42.00	R 1 300.00	2 x 18W LED Tube	48	R 802.00
	76	R 18.00	2 x 28W (T5)	16.8	R 42.00	R 1 300.00	2 x 18W LED Tube	36	R 802.00
3 x 36W Fluorescent tube (T8)	132	R 18.00	3 x 28W (T5)	43.56	R 42.00	R 1 400.00	3 x 18W LED Tube	75	R 802.00
4 x36W Fluorescent tube (T8)	173	R 18.00	2 x 54W (T5)	59.4	R 48.00	R 1 550.00	4 x 18W LED Tube	98	R 802.00
1 x 40W Fluorescent tube (T9 circular)	54	R 35.00	ECG	49.33			1 x 18W LED Tube	34	R 802.00
1 x 58W Fluorescent tube (T8)	71	R 21.00	35W (T5)	70.40	R 35.00	700	1 x 25W LED TUBE	46	R 1 166.00
2 x 58W Fluorescent tube (T8) - with CCG and ECG	142	R 21.00	2 x 35W (T5)	68.02	R 35.00	R 950.00	2 x 25W LED TUBE	84	R 1 166.00
	122	R 21.00	2 x 35W (T5)	48.30	R 35.00	R 1 250.00	2 x 25W LED TUBE	65	R 1 166.00
2 x 65W	159	R 35.00	2 x 49W (T5)	55.70	R 72.00	1400	2 x 25W LED TUBE	100	R 1 166.00
1 x 75W	92	discontinued	49W (T5)	40.05	R 72.00	R 950.00	1 x 25W LED TUBE	60	R 1 166.00
1 x PL13	16	R 25.00	ECG	2.35	R 34.00				
2D 16W Fluorescent	20	R 32.00	ECG	2.72	R 28.00				
2D 22W Fluorescent	27	R 32.00	ECG	3.74	R 36.00				
100W incandescent	100	R 12.00	23W CFL	77	R 38.00		NOTE: the lamp prices below are for whole new fitting; each of these lamps can be replaced with a 9.5W LED lamp at a cost of R365.00 each. However, note that lamp life of each LED lamp is 35000 - 50000 years		
1 x 18W CFL Downlight	22	R 25.00					1 x 12W LED lamp	5	R 609
2 x 13W CFL Downlight	32	R 25.00					1 x 12W LED lamp	14	R 609
2 x 18W CFL Downlight	44	R 25.00					1 x 12W LED lamp	27	R 609
2 x 26W CFL Downlight	63	R 32.00					1 x 19W LED lamp	36	R 1 048
35W Halogen Downlight	42	R 30.00					1 x 6W LED lamp	33	R 495
50 Halogen Downlight	60	R 21.00					1 x 12W LED lamp	43	R 695

Source: SEA 2012, Effiicent Public Lighting Guide

Integrated Demand Management funding for energy efficiency interventions

For a number of years Eskom has had a programme for financially supporting the application of measures which reduce the quantity of electrical energy consumed by customers. This applies to all electricity consumers, not only those who are directly connected to Eskom.

Today the overall programme is known as Integrated Demand Management and has several components which are applicable to various sectors – residential, commercial, industrial, and agricultural. In some cases the consumer can make direct application for the funds but processes are generally technical and lengthy. It is usually best to engage a reputable and experienced Energy Services Company (ESCo) to undertake the application, if not the installation work as well.

The programme options that are more suited to commercial buildings are known as Standard Product and Standard Offer. There is also the Demand Response Aggregated Pilot Programme which requires consumers to switch off previously determined loads at fixed predetermined times for payment at a fixed rate. The other two are much more in evidence. The Standard Product is for smaller potential savings, up to 250kW, for a limited number of products. These are mostly lighting but shower heads and heat pumps are included. Perhaps the most used option is the Standard Offer. Here the minimum saving required is 50kW and the maximum permitted is 5MW. Different technologies and different sites can be 'bundled' in order to achieve the minimum saving.

The Standard Product application is based on an online spreadsheet. Savings for each technology and component therein are predetermined and there is a further cap on the maximum that can be claimed. The Standard Offer is more flexible and pays energy saving at R0.42-R0.70/kWh for energy reductions between 06.00am and 22.00pm, Monday to Friday. The contract runs for three years and 70% of the 3-year value is paid on completion and verification of the savings intervention. Thereafter it is 10% at the conclusion of 1-year intervals, provided the savings have been maintained.

Eskom occasionally revises their offers and their website should be consulted before attempting to proceed with any of the schemes. Also note that Eskom funds are not available retrospectively; application must be made in advance of any intervention.

Useful links and sources

The Green Building Council of South Africa: Link: http://www.gbcsa.org.za

Eskom Integrated Demand Management Programme: Link: http://eskomidm.co.za

Independently vetted list of ESCOs operating in Cape Town: Link: http://www.escos.co.za