DUMONT D'URVILLE
ENERGY MANAGEMENT SYSTEM

Pierre ALAIN (1), Patrice GODON (1), Antoine GUICHARD (2)

1) IFRTP, BP 75, 29280 Plouzané, France
2) Latitude Technologies Pty Ltd, PO Box 841, Sandy Bay, Tasmania 7006, Australia

INTRODUCTION

Global energy management has become a priority in the design and operation of Antarctic stations for both financial and environmental reasons. It usually translates into three different but combined courses of action:

- To minimise needs
- To optimise production and transmission efficiency
- To increase renewable energy input

The French Institute for Polar Research and Technology (IFRTP) and its parent organisation the French Polar Expeditions (EPF), successive operators of Dumont d'Urville Station, have always practised a progressive, long-term energy management strategy for the station. For many years it focused on 'minimising' and 'optimising' using simple yet effective design and operational procedures and decentralised analog control systems.

A few years ago, IFRTP started the progressive introduction of a centralised, computerised energy management system, Énergie Système™, capable of controlling and coordinating the three courses of action. This new system already manages successfully most 'minimising' and 'optimising' functions previously put in place but with a significant increase in flexibility and efficacy.

Énergie Système™ is built around a central processing unit (CPU) communicating via a single Lonworks™ bus with Input/Output (I/O) modules placed around the station. The parameters (temperatures, on/off states, etc…) to take into account are read by sensors connected to the input channels of the modules and queried by the CPU. The CPU sends its control orders are sent through the output channels of the modules. A PC communicating with the CPU via RS232 or modem is only used as a programming or monitoring terminal.

The Lonworks™ bus operates at 78kps over a single shielded twisted pair of 2,000 m maximum length. The CPU identifies unambiguously each I/O module connected to the bus by reading the module's unique serial number.

The CPU can manage a total of 148 inputs and outputs and up to 255 CPUs can be connected together via a RS422 serial link to create a wider system managing up to 37,740 points.

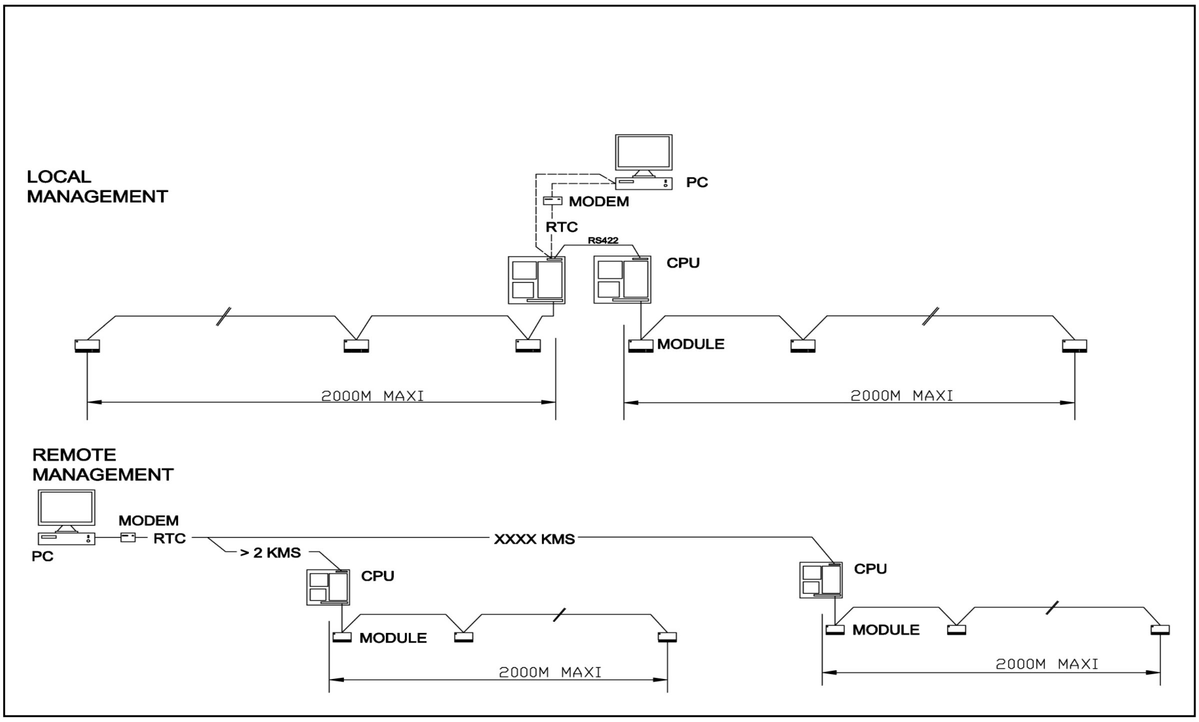

Figure 1 : Énergie Système™ hardware structure

The system sends its orders to adjust valves or to switch loads on or off according to the program loaded in the CPU. The program is written a versatile, simple programming language, can use as variable any parameter input into any module and can send an order to any output channel of any module. It is not restricted to predefined functions, can easily be modified on site and allows recording of all variables for later analysis and fine-tuning of the system.

The system first took over the control of the electrical load shedding, designed to ensure an optimal energy production efficiency. It significantly increased the range and flexibility of the shedding function but also provided a finer control of a large number of electrical appliances and contributed to a much better management of the load. The system is now also controlling some non-electrical thermal loads and provides an efficient, time and weather dependent control of internal building temperatures.

The scope of the system will keep expanding over the next few years. It will notably provide advanced control capabilities of the electrical and thermal load mix, paving the way to the effective management of increasing renewable energy contributions.

1) STATION ENERGY SYSTEM OVERVIEW

1.1 - Structure and Operating Principles

Dumont d'Urville is a fairly compact, efficient station with limited site services infrastructure.

The Main Power House (MPH) accommodates three Diesel generator sets of 144 kW rated electrical output and a fresh water production unit where seawater is desalinated in an evaporator. Most of the waste heat recovered from the generator sets out of both jacket water and exhaust gases is used within the building in the evaporator. Occasional excess heat is injected in a primary heating hot water (HHW) loop sent out of the MPH to heat surrounding buildings. If there is insufficient heat recovery for desalination, additional heat is provided within the building by a boiler and if necessary by electrical heating elements.

The MPH is exporting electrical power to the entire station but is exporting fresh water and brine (the desalination by-product) to only a small number of selected buildings. Freshwater is delivered on demand while brine is constantly delivered as it is produced and rejected through the sewage system.

Only small shelters are heated electrically. All major buildings are heated directly or indirectly with Diesel-fired boilers. Some buildings are equipped with their own standalone boiler. The other buildings are serviced by one of two 'primary' heating hot water (HHW) loops reticulating hot water from building to building. The first primary HHW loop is fed and controlled by a central boilers' room housed in a dedicated building. The second primary HHW loop is fed and controlled by the MPH and uses any potential heat surplus of the MPH.

Each building has an internal, 'secondary' closed HHW loop feeding radiators. The secondary loop receives heat either from a primary loop through an exchanger or directly from a standalone boiler. Each secondary loop is always equipped with an in-line electric heating element. This allows isolation of the loop but will also in the future allow an advanced, optimised management of the electrical / thermal mix of the station load. In buildings where a domestic hot water circuit is needed this circuit operates off the 'secondary' HHW loop.

Relative to the Lower Heating Value (LHV) of the Special Antarctic Blend (SAB) Diesel fuel used at the station (9.8 kWh per litre) the MPH generator sets have an efficiency of about 37% towards electrical production and 42% towards thermal production, that is a combined "cogeneration" efficiency of 79%, providing of course that all the heat generated is used and does not require much electricity (for example in pumps) to reach its point of use. Boilers have a similar efficiency close to 80%, all towards thermal production.

The guiding operating principles used at Dumont d'Urville are:

(a) To limit the electrical load to ensure that the waste heat recovered on the generator sets does not exceed the heat needed within the MPH

(b) To control the electrical load so that only one generator set is ever used at any given time and that this generator set operates within its optimal load range

(a) was achieved through the minimisation of the station's electrical needs and the design of a desalination unit with adequate heat input requirements.

(b) was in the past achieved through the use of an electromechanical load shedding system capable of switching off a limited number of non-priority electrical loads. These loads had to be switched back on manually by the person on watch at the MPH. The load shedding is now entirely controlled by the computerised energy management system and acts on a much larger number and variety of electrical loads.

1.2 - Typical Loads and Fuel Consumption

Over the four years 1996-1999 the average station electrical load was around 75 kW. Using the assumed efficiencies detailed before, the average station thermal load was around 225 kW broken down into 90 kW recovered on the generator sets, 35 kW produced by the MPH boiler for additional heat input into the desalination plant and 100 kW produced by the various boilers heating the buildings. That gives an average total (electrical + thermal) station load of 300 kW.

The corresponding annual Diesel fuel consumption was 342,000 litres broken down into roughly 192,000 litres for the generators, 38,000 litres for the MPH boilers and 112,000 litres for the buildings' boilers. The station overall energy production efficiency is around 79% (energy production relative to LHV energy content of fuel consumed).

This is for a station comprising 2,800 m^2 / 8,400 m^3 of heated building space and producing an average of 4,257 litres of fresh water each day by desalination. The average station occupancy is 39.35 persons or 14,375 person-days a year. This gives an average per occupant of: 1.9 kW electrical load, 5.7 kW thermal load, 7.6 kW total load, 108 litres of fresh water per day and 23.8 litres of Diesel fuel per day.

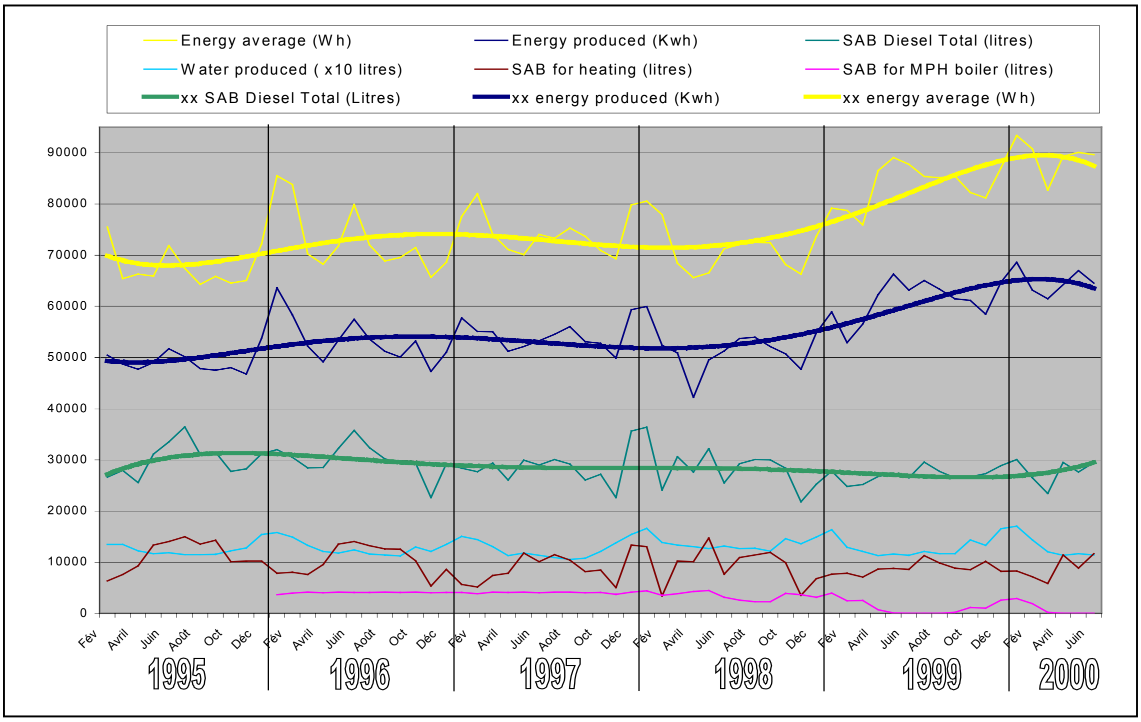

Figure 2 – Energy summary 1996-1999

2) MINIMIZING NEEDS

A large proportion of an Antarctic station's energy needs is for space heating. The minimisation of space heating needs at Dumont d'Urville has focused both on the increase of buildings' thermal properties (good insulation and reasonable size) and on the optimisation of internal temperature control (time dependent optimal temperatures corrected according to meteorological conditions).

Another significant proportion of energy needs is for lighting, especially during the long, dark winter months. At Dumont d'Urville, it accounts for about 25% of the electrical load.

The lighting load is minimised through the use of efficient lighting appliances, timers and motion detectors.

2.1 - Increasing building thermal properties

Dumont d'Urville Station includes six generations of buildings. It started with fairly basic timber constructions and evolved through trial and (hopefully few) errors to a couple of thermally efficient, durable and low ground impact building concepts each adapted to a category of use.

Generation 1 dates back to the early 1950s. The buildings were constructed entirely in timber. There is one such building left on station, "Base Marret". Of heritage value, the building has been restored and is used occasionally.

Generation 2 "AGI" dates back to the late 1950s, the times of the International Geophysics Year (in French Année Géophysique Internationale or AGI). The buildings consisted of a prefabricated steel shell with an internal insulation lining. There is no building of this type left.

Generation 3 is similar to generation 2 but with improved internal insulation lining. There are five of these buildings left. They are currently the subject of a significant renovation and upgrade program (see further).

Generation 4 "SPAIR" appeared in the 1960s and was a real innovation. A steel frame, usually elevated on stilts, was holding from the outside a continuous shell of single-skin composite panels with no thermal bridge. The composite panels were 90mm reinforced sandwich panels made of fibreglass and non-flammable, rigid PVC foam.

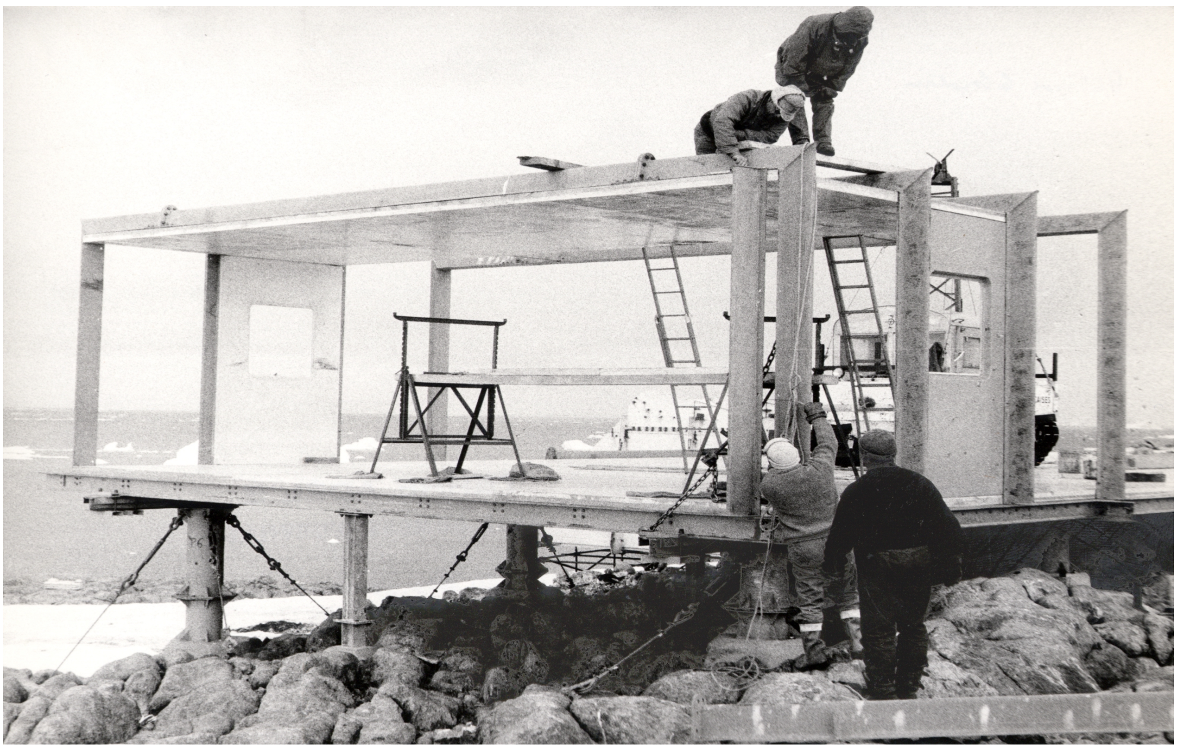

Figure 3: Generation 4 "SPAIR" building under construction

The main advantages of this concept are a high degree of prefabrication, the panels coming all ready with doors and windows openings fitted, a very low volume and weight of materials to be shipped and handled and very easy to handle individual elements which allows a construction process with little impact on the surroundings. The main disadvantages are poor soundproofing and wind induced vibration filtering properties, the high cost of the panels and a durability of the external skin now well superseded by new materials.

Built between 1963 and 1970, the six 'SPAIR' buildings built are now between 30 and 37 years old and have resisted well to many storms including one with winds over 315 km/h. The six buildings are still in operation and represent in terms of floor area about half of the buildings permanently heated.

Generation 5 "Siporex" appeared in the very early 1990s. Buildings are built with light, non-flammable and non-combustible "Siporex™" cellular concrete blocks glued together and protected from the weather by a thin external cladding.

Figure 4: Generation 5 "Siporex" building under construction

The main advantages are a very high proportion of natural, ecological materials (basically sand and limestone), good thermal insulation and soundproofing properties and a very stable structure not prone to wind induced vibrations. This creates very comfortable buildings providing a high quality living environment. It must be noted that the relatively light weight of the cellular concrete still allows construction of the buildings on piles for minimal impact on the ground. The main disadvantages are the requirement for a high volume of building material (200mm walls are needed to give the same insulation than the 90mm composite panels of the 'SPAIR' buildings) and a labour intensive construction process including significant finishing work.

Generation 6, first used in 1998 for storage buildings, combines many advantages of previous generations. A stable, well insulated load-bearing slab base is constructed on piles with 150 to 200mm of cellular concrete blocks sandwiched between two layers of concrete, a lower, reinforced structural slab poured in formwork and an upper, finishing concrete floor. A steel structure is erected on the slab base, clad on the outside by plastic-coated steel sheets and in the inside by sandwich panels. The sandwich panels are either M1 rating (non-flammable) fibreglass-reinforced polyester and polyurethane foam panels or M0 rating (non-flammable and non-combustible) steel and rockwool panels. The space in between the cladding and the internal panels is filled with insulation, either injected M1 foam or M0 rockwool sheets.

The main advantages of this concept are a reasonable volume and weight of materials, a fairly quick and easy construction, little finishing work and a stable, sturdy and well-insulated platform that can be mounted on piles for a minimal impact on the ground. The only slight disadvantages are soundproofing and wind induced vibration filtering properties a bit lower than for generation 5 "Siporex™".

Figure 5: Generation 6 building

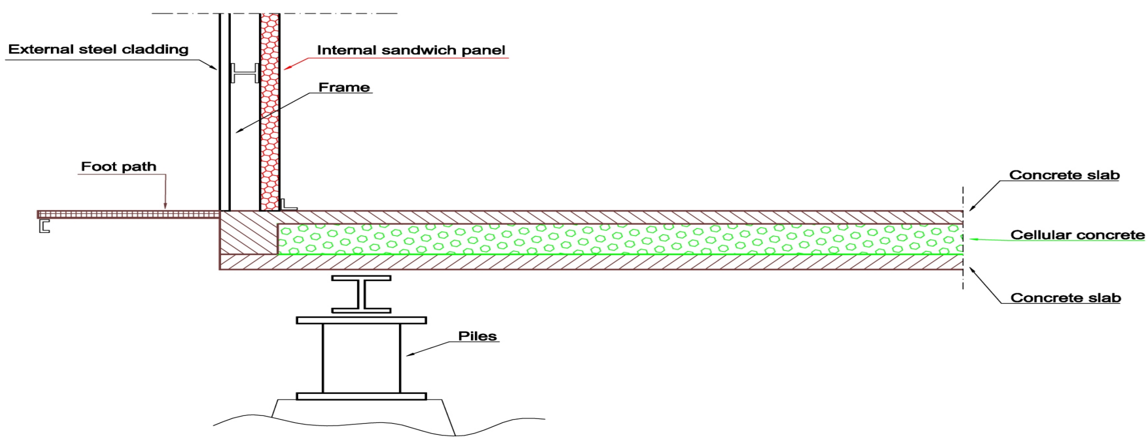

Figure 6: Cross section of a Generation 6 building

The plastic-coated steel sheeting used in the cladding of the last two generations of buildings is a very durable, high quality product offering excellent resistance to the weather. It is galvanised and coated on the external side by a very strong plastic coating applied early in the fabrication process, before any shaping of the panels. It suffers less alteration than both the old steel claddings and the fibreglass panels.

Figure 7: Generation 3 building after renovation

This plastic-coated sheeting is used in a renovation program now under way for buildings of generation 3 and 4 and destined to both extend significantly the buildings life and further increase their thermal properties. The buildings are clad on the outside with the plastic-coated steel sheeting on a simple steel frame and the space created in between the new cladding and the old external skin of the building is filled with insulation, either injected M1 foam or M0 rockwool sheets.

In the near future, Generation 5 should be used for frequently occupied buildings, especially for a future accommodation building, and Generation 6 should be used for storage buildings.

We are also following with interest the apparition of a new expanded-glass material developed by a unit of the French National Centre for Scientific Research (CNRS) and to be manufactured by a French-Belgian company. This material has good insulation properties, is inert and non-combustible. It is also a natural, ecological material made exclusively of silica. It is manufactured by expanding crushed recycled glass.

2.2 - Optimising internal temperature control

There are various reasons for heating a building, such as providing a comfortable temperature for users, a satisfactory operating temperature for equipment or an ideal storage temperature for food or other supplies. It is important to satisfy these requirements and just these requirements. Any small temperature excess might have a cascading effect generating a large increase in heat consumption, for example if a dissatisfied user regulates his room temperature by opening a window. Any significant temperature excess or deficit might be detrimental to the building's functions, for example by indisposing personnel, causing equipment malfunction or degrading supplies.

The system in place at Dumont d'Urville for many years involved regulation at a constant, optimal room temperature using individual, temperature controlled valves. The building heating hot water circuit reticulated water at a fixed temperature and the flow of this water through each radiator was adjusted automatically by a temperature controlled valve. Each valve was set at the desired room temperature then sensed the difference between this desired room temperature and the actual room temperature and adjusted the flow of water through the radiator to reach and maintain the desired temperature.

This system has the inconvenience of maintaining a constant 'normal operating temperature' while lowering room temperature when the building is not occupied can allow significant energy savings. Using an additional, simple time dependent control is often of limited interest due to its incapacity of adjusting to varying thermal inertia in changing weather conditions. Variations of the external weather conditions, mainly temperature and wind speed, induce variations in the thermal losses through the building's skin and hence variations in the speed at which the heating system can respond to and adequately follow a temperature control rule.

The computerised management system Énergie Système™ now provides an additional, versatile layer of control used to optimise time evolution of room temperature.

The first step is to analyse the building usage and establish a time dependent function of the desired room temperature. This typically consists of a plateau with the 'normal operating temperature' during normal times of human presence in the building and lower 'standby temperatures' during other times.

Ensuring close compliance of the actual room temperature with the desired room temperature function in varying weather conditions can then be achieved by the combination of two actions:

(a) Adjusting the temperature control rule according to weather conditions by allowing longer transition times when thermal losses are higher (see Figure 8).

(b) Increasing the temperature of the heating hot water circuit, that is improving the response capability of the heating system, both when thermal losses increase (see Figure 9) and/or when the difference increases between the control temperature to reach and the actual room temperature. The adjustment of the water temperature is done through a three-way mixing valve.

Énergie Système™ manages and coordinates the different rules with input from a wind monitor and outdoor air temperature sensor connected to analog channels of the system. Figure 8 shows an example of time dependent temperature control rule adjusted for various wind speeds. Figure 9 shows an example of heating hot water (HHW) temperature rule as a function of both outdoor air temperature and wind speed.

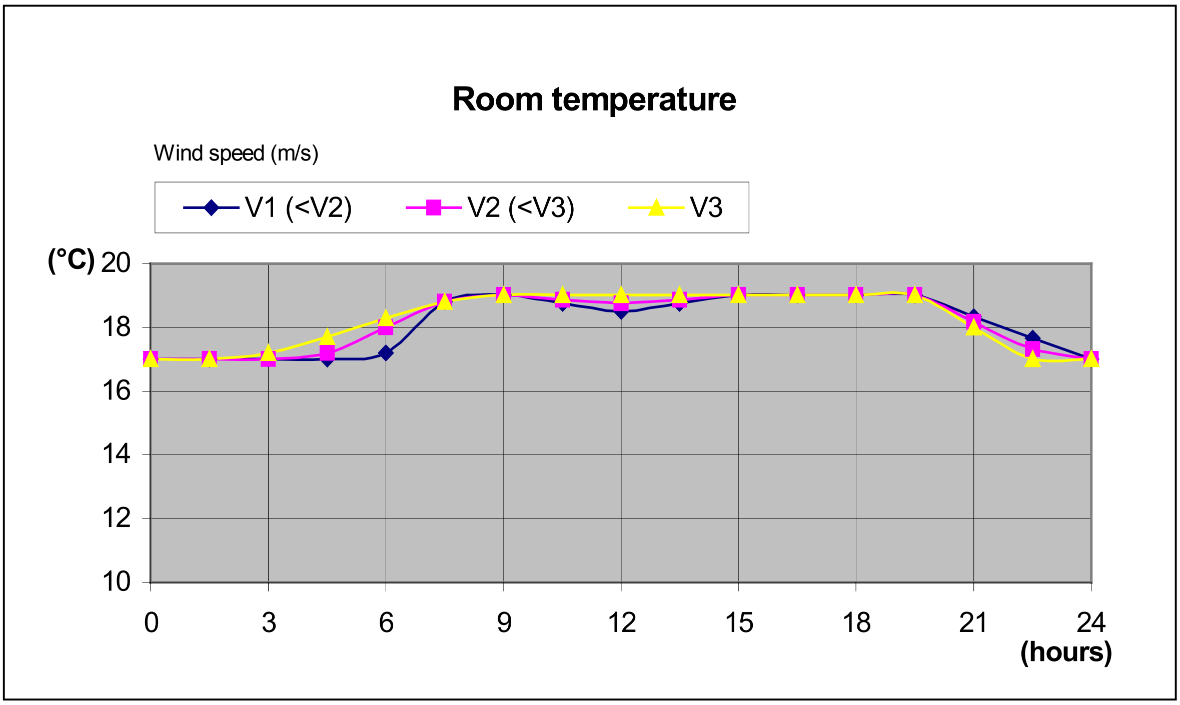

Figure 8: example of time and weather dependent room temperature control rule

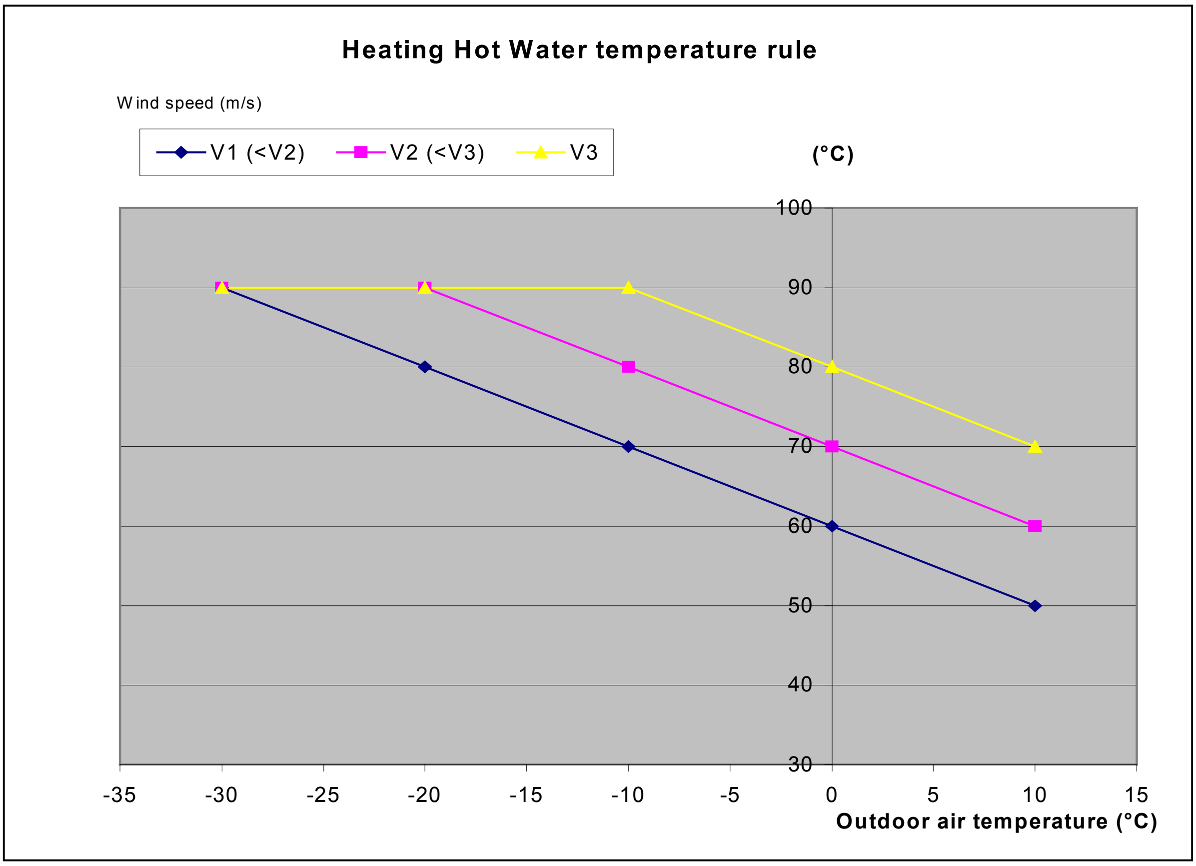

Figure 9: example of weather dependent HHW temperature rule

It must be noted that a traditional, individual temperature controlled valve is still mounted on each radiator where it effectively provides for each local area a fine, independent control of the ‘normal operating temperature’. When the system wants a lower room temperature it decreases the temperature of the heating hot water which causes the individual valves to increase the flow through the radiator until it reaches its maximum flow. From then on, Énergie Système™ has the effective control of the room temperature and can adjust it to any temperature lower than the ‘normal operating temperature’.

2.3 - Minimising Lighting Loads

Efficient lighting is now used extensively throughout all the buildings occupied regularly. To avoid having lights left on when not needed, the common areas are equipped with a combination of timers and infrared motion sensors which switch the lighting off after a certain time during which no movement has been detected.

3) OPTIMIZING PRODUCTION AND TRANSMISSION EFFICIENCY

3.1 - Cogeneration

The current MPH building built in 1963 included cogeneration right from the start with heat recovered from the engine jacket water used in the evaporator for the desalination process. Close to a third of the fuel’s energy content can be recovered relatively easily from the engine jacket water through its cooling system. Significantly less, usually well under a sixth of the fuel’s energy content, can be recovered from the exhaust gases and it requires more complicated equipment. This is why it was initially decided in the 1960s to only recover heat from the jacket water.

The amount of heat recovered from the jacket water was under normal circumstances close to the amount needed only a few metres away by the evaporator to assist the desalination process. A standalone boiler was producing any additional heat required by the evaporator.

In recent years the apparition of newer equipment combined with an increased focus on fuel economy and environmental issues triggered the decision to add exhaust heat recovery capabilities to the MPH. This was done during a significant upgrade of the MPH involving the installation of a new generation of generator sets.

Figure 10 shows the principle of the new MPH heating hot water system composed of three independent circuits separated by heat exchangers.

- the jacket water heat recovery and evaporator heating circuit (JW) is in red
- the exhaust heat recovery circuit (EX) is in purple
- the intermediate transfer and primary loop circuit (TR) is in green

This structure allows an optimal use of all the heat recovered from the generators either within the MPH or via the primary loop in nearby buildings. The JW circuit picks up heat from the engines’ jacket. If necessary it can pick up additional heat first from the TR circuit then from electric heating elements. It delivers heat to the evaporator. The EX circuit picks up heat from the exhausts and delivers it to the TR circuit. The TR circuit picks up heat from the EX circuit plus if necessary from a the MPH boiler. If necessary it delivers heat to the JW circuit through the heat exchanger. It then delivers heat to nearby buildings via the primary HHW loop plus

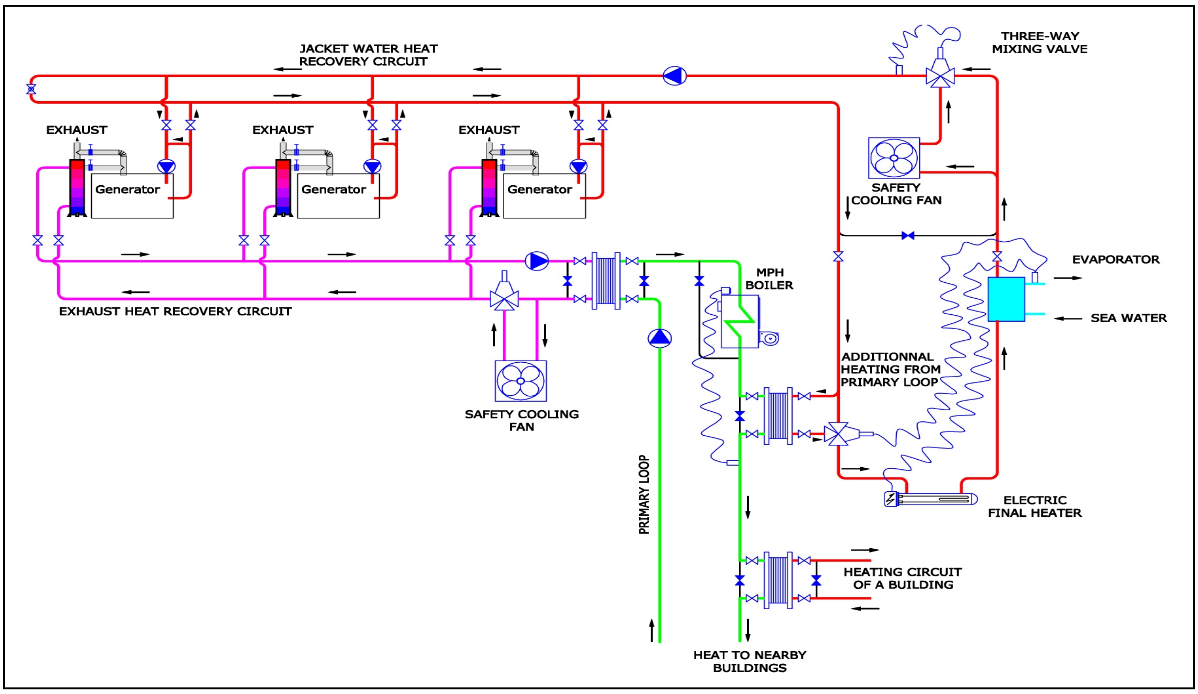

Figure 10: MPH Heat Recovery and Heating Hot Water Circuits

The JW circuit primarily picks up heat from the engines' jacket and delivers it to the evaporator where it is used in the desalination process. If the heating water arrives at the evaporator under a certain temperature threshold (70°C), a three-way mixing valve diverts some of the water to the heat exchanger with the TR circuit where it can pick up additional heat originating from the EX circuit and/or from the boiler. If the seawater in the evaporator is under a certain temperature threshold (69°C) the electric heating elements switch on by 12 kW increments to increase the heating water temperature. It must be noted that when the electric heating elements come on it increases the load on the generators and hence increases the amount of heat recovered on both exhaust and jacket water circuits, quickly reducing the need for the operation of the electric elements. If the heating hot water returns to the engine jackets over a certain temperature threshold (80°C) , that is when there is not sufficient engine cooling, a three-way mixing valve diverts some of the water to a cooling fan. A bypass allows restriction of the circuit to the engine jackets and the cooling fan, providing if necessary a simple cooling system with no heat recovery.

The EX circuit primarily picks up heat from the condensers mounted on the exhausts and delivers it to the TR circuit. If the heating hot water returns to the exhausts over a certain temperature threshold, that is when there is not sufficient exhaust cooling, a three-way mixing valve diverts some of the water to a cooling fan. A bypass allows restriction of the circuit to the condensers and the cooling fan, providing if necessary a simple cooling system with no heat recovery.

The TR circuit is a versatile multifunction circuit. It allows transfer of heat from the EX circuit to the JW circuit if needed, allows the production of additional heat with the MPH boiler if necessary and allows the export of excess exhaust heat out of the MPH to nearby buildings via the primary loop. If the heating hot water about to exit the building is under a certain threshold temperature (80°C) the MPH boiler comes on to provide additional heat. A three-way valve to be installed just before the primary loop exits the MPH will allow the regulation of the loop's HHW temperature to minimise heat losses.

3.2 - Management of the Electrical Load

The ideal situation would be to have a fixed, constant electrical load in the optimal range of the generator set. It would provide the most efficient operation of the generator plus a stable, easily manageable heat recovery and all components and functions could be sized accurately.

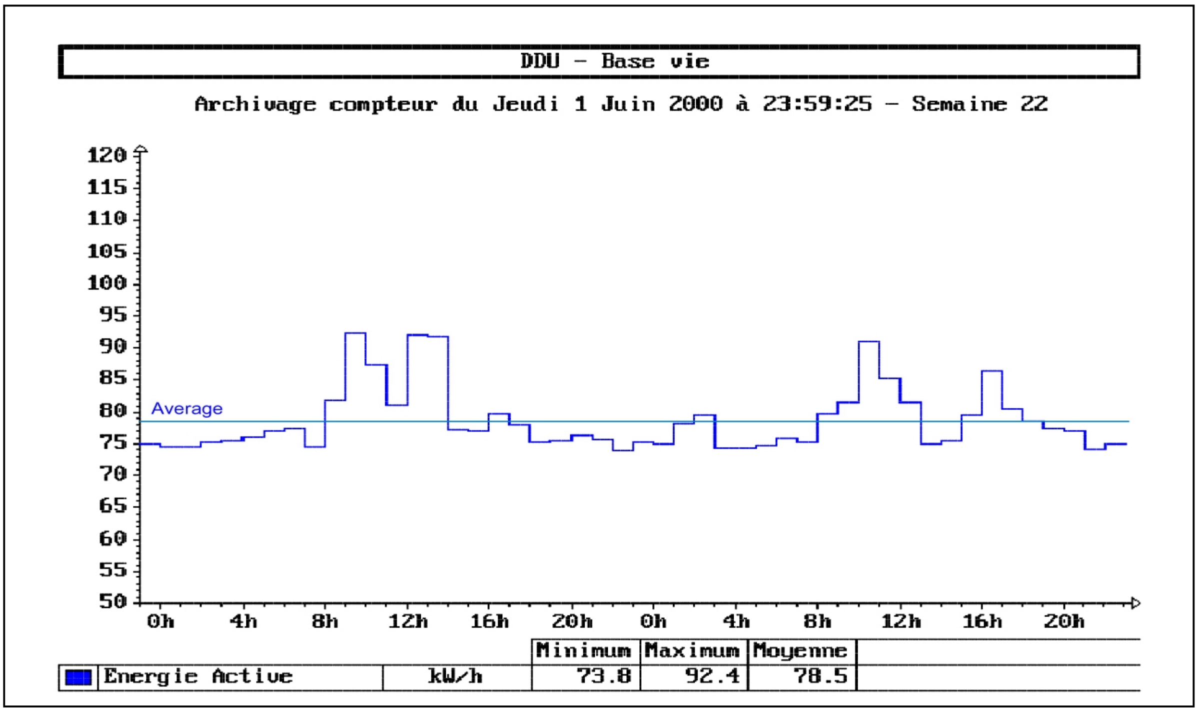

Figure 11: Generator output without load shedding system

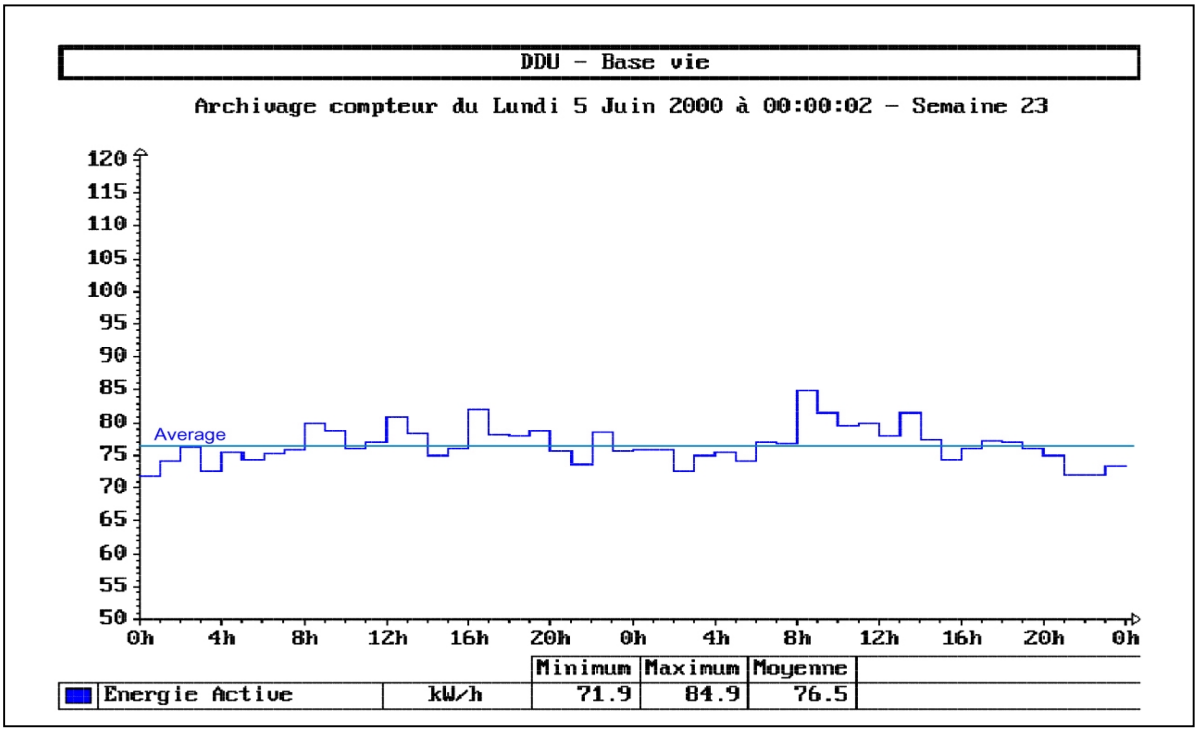

Figure 12: Generator output with load shedding in function

A basic load shedding system only manages the suppression of most load peaks to avoid excessive transitory power surges, protect the generators from overloading and reduce the need for starting up an additional generator. It usually works by switching off a limited number of non-priority appliances in a fixed, predetermined order with the same lowest priority appliance always switched off first. The switching off is triggered when the total load goes over a certain threshold.

The more advanced load shedding function of the Énergie Système™ actually enables a sophisticated, uninterrupted management of the load by sequencing the switching of a large number of electrical appliances. It effectively creates an additional 'load management' function. It operates within a series of individual rules established for each appliance. The rules are designed not to interfere with the satisfactory operation of the end-service it provides and to ensure satisfaction of the end-user.

The appliances involving a thermal process with inherent inertia are the best candidates for management by the system, the more inertia the better. Such appliances include for example electrical heating of small shelters, ovens and autoclaves and heating functions of dishwashers, washing machines and clothes dryers. These appliances have an optimal operating point and an acceptable operating range around the optimal point declared in the system. The optimal point and acceptable operating range can vary in time on a daily, weekly or annual basis but can also vary according to other parameters sensed by the system, such as meteorological conditions or room temperatures.

With control over a wide range of these appliances, the system can finely sequence their operation so that the total load stays as constant as possible and each appliance fluctuates within its acceptable operating range.

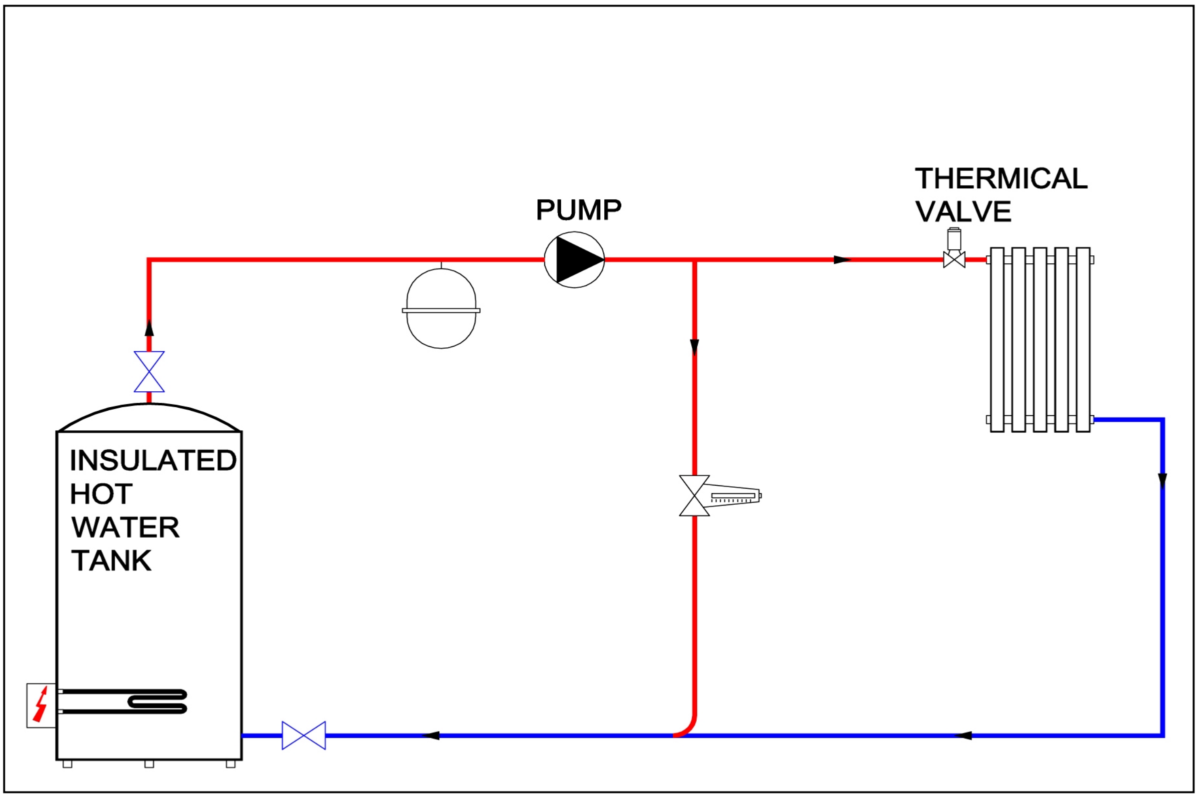

Figure 13: Example of a heating using a hot water tank

To take further advantage of these new capabilities, some appliances and services will where possible be modified to increase their thermal inertia. This can significantly increase the potential of the system. For example, isolated shelters were heated by conventional, dry convector heaters. The thermal inertia of the service is restricted to the limited inertia of the air in the shelter. Many shelters will be progressively equipped with hot water based heating system offering a much higher inertia. The electric heating elements will heat a 500 litre hot water cylinder that will in turn feed hot water into a wall. The room temperature is controlled by a combination of the hot water temperature and a variable flow through the radiator. This offers both a significant thermal inertia and a wide operating range for the water temperature, providing a flexible load highly useable by Énergie Système to manage the station load.

The system can also manage some non-priority on-off type appliances that can be either disconnected for certain predefined time periods where high loads are expected or can if necessary be switched off when operating without significant inconvenience. This includes for example the 11kW garbage compactor. The control of these appliances participates to the basic load shedding function (avoiding power surges and generator overloading) but contributes little to the more advanced load management function.

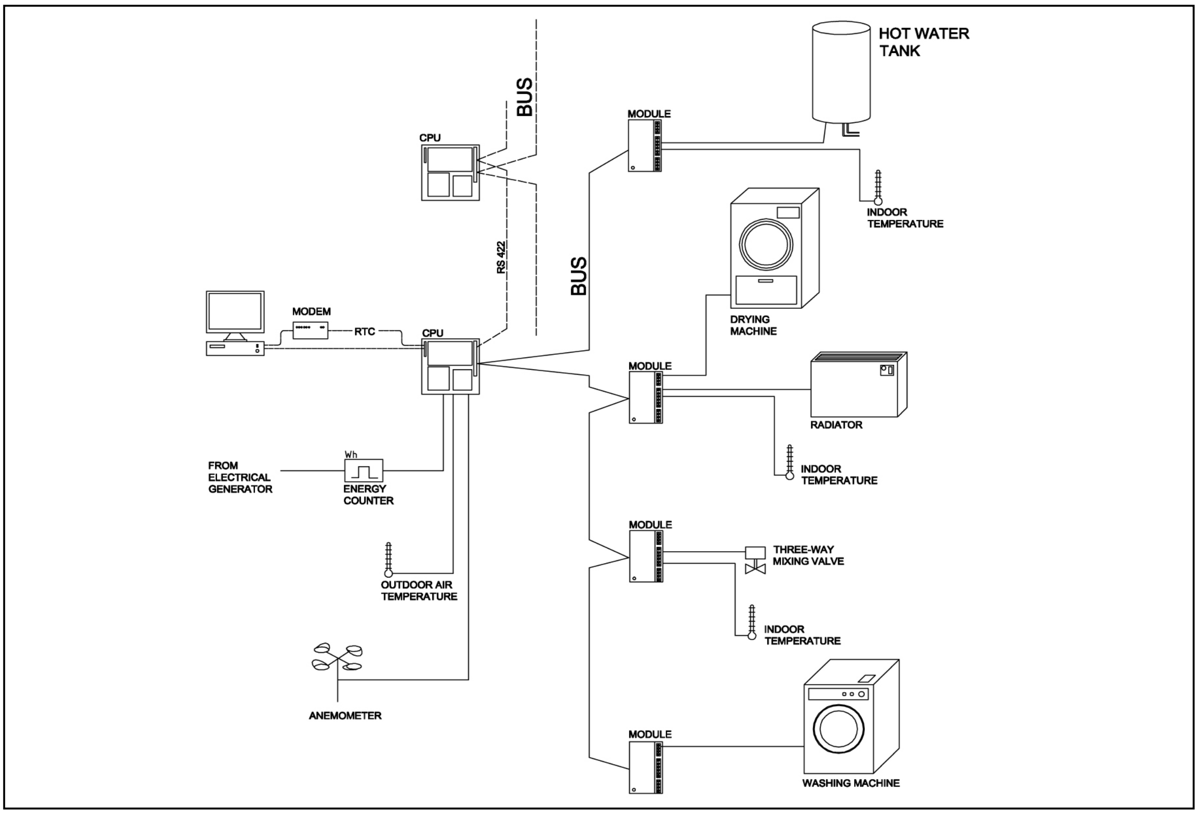

Figure 14 : Structure of the electrical load management circuit

The planned introduction of this load shedding and load management functions of the Énergie Système™ allowed a more precise sizing of the new generator sets and prevented a costly over-sizing of the infrastructure. The effective operation of the system now allows a relatively stable operation of the MPH on one single generator at the lower limit of its optimal range, leaving room for possible future activity increase on station. The past, occasional need for operating two generator sets in parallel has virtually disappeared. It resulted in fuel savings due to an increase in production efficiency. It also resulted in parts, lubricants and man-hours savings due to a decrease in engine hours.

4) INCREASING RENEWABLE ENERGY INPUT

Once station energy needs have been minimised and the power system production and transmission efficiency have been optimised, the obvious way of further reducing fuel consumption and increasing sustainability is to input into the power system as much energy as possible produced locally from renewable sources such as wind or solar radiations.

A solar, photovoltaic array is operational at Dumont d'Urville but restricted to an isolated, standalone set of buildings located at Cape Prud'homme and opened only in summer. The major inconvenient of solar power for year-round Antarctic stations is its marked seasonal variability with negligible output over the long winter. It is not envisaged at this stage to install large solar arrays for the main station.

Dumont d'Urville experiences fairly strong and consistent winds throughout the year with a long term wind speed average over 10m/s. There is a good potential for significant wind generation capacity and some models of wind generators are currently under consideration for use at the station. A new concept of wind generator developed by a French company seems well suited to the station's conditions and a prototype unit should be tested on site in the near future.

As shown in previous sections of the paper, the good, efficient operation of the entire power system relies on preserving an appropriate, stable electrical load and on maintaining an adequate balance between the electrical and thermal loads.

If the traditional fossil fuel based power generation systems used at the station provide power 'when needed', renewable energy sources provide by essence power 'when available' and are characterised by a high level of temporal variations. This means that installing large amounts of renewable energy production capabilities will induce the introduction into a well-balanced system of an uncontrollable and highly variable quantity of power. This will unbalance the station system and jeopardise its efficiency unless the system is capable of a high level of load management including a high level of control of the balance between the electrical and thermal components.

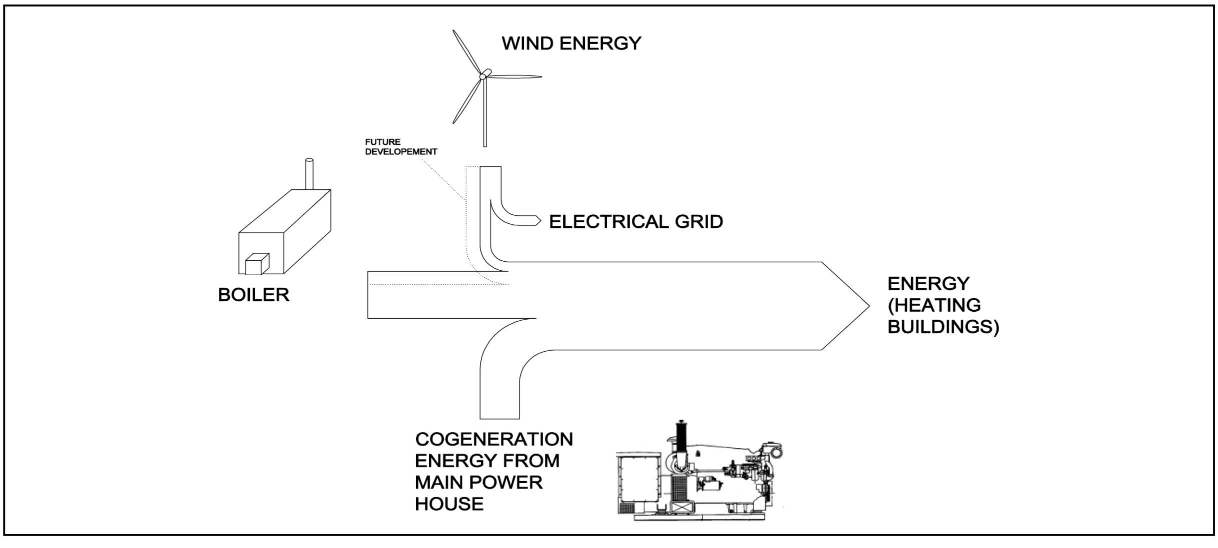

Figure 15 : Renewable energy input

For example, a direct input of electricity from wind generators into the electrical grid of a system where electrical and thermal loads are separated could force the generators to run for long hours well below their normal operating range causing poor generation efficiencies and excessive engine wear.

On the other hand the input of electricity from wind generators into electric heating elements within a similar system at times of low thermal needs, for example in summer, may exceed the low amount of heat needed in complement of the generator heat recovery causing a reduction of the effective cogeneration efficiency.

Of course, such scenarios may still reduce the overall station fuel consumption but they imply a loss of energy and it is important to remember that although renewable sources like wind and solar radiation are free, converting them into power with solar arrays or wind generators is not free. Any loss of energy will correspond to an increase in the unit cost of energy production.

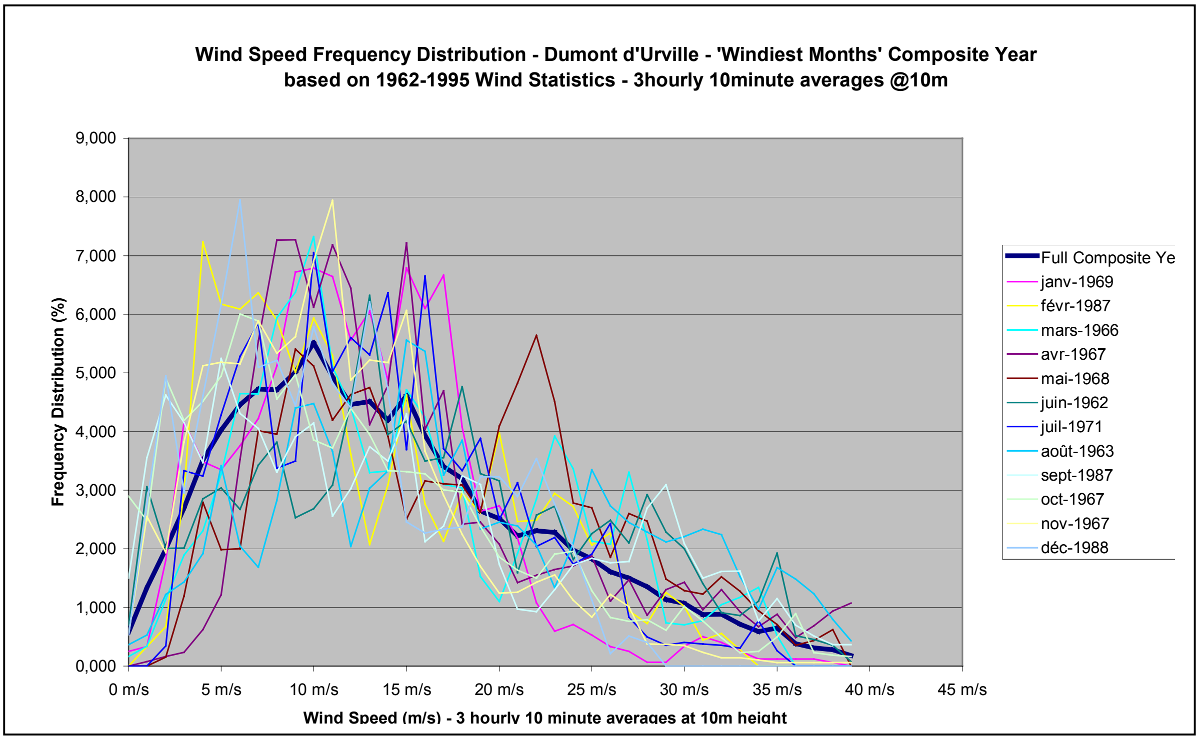

Figure 16: Wind potential

The development of the Énergie Système™ load management function will further allow a dynamic distribution of the load between electrical and thermal components and offer a highly dynamic, flexible power environment where renewable energy input can be used efficiently and smoothly.

CONCLUSION

Dumont d'Urville research station is supported by an efficient, well balanced energy supply system. The recent introduction of a computerised energy management system has contributed to further reductions of the energy requirements and further gains in generation and transmission efficiencies. It also allowed a fine estimate of the needs for infrastructure upgrade, avoiding costly oversizing of new installations. The continuing expansion of the system will provide further improvements and will pave the way for a smooth, efficient increase of renewable energy contributions.

06/07/2000

DUMONT D'URVILLE
ENERGY MANAGEMENT SYSTEM

Index